young cities

Developing Urban Energy Efficiency

Tehrān-Karaj

Young Cities Research Briefs | 12

# Relationship between U-Values, Energy Demand and Life Cycle Costs in Office Buildings

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# Abstract

This volume of the Young Cities Research Briefs presents the New Generation Office Building, as one of the pilot projects within the Young Cities Research Project, and describes the energy and cost matters using different thermal resistances in the building envelope. It includes two chapters: the first with an alternative design of the New Generation Office Building as a very low energy office building. The chapter includes the main objectives of the pilot project, some of the concepts applied as well as the architectural plans.

The second chapter studies the behavior of the energy demand and the life cycle costs of the office building with different U-values. The aim here was to determine the optimum U-value for the building in the warm and dry climate of Hashtgerd New Town, Iran. Dynamic energy simulation is used to calculate the heating and cooling energy demands of the New Generation Office Building with nine different building envelopes. The results show the positive effects of thermal insulation in winter, but also the negative impacts in summer, which calls for special provisions to the building design for these months. Concerning the cost analysis, the costs associated with the nine case studies—including the initial, maintenance, energy and life cycle costs—are calculated for a 15-year period and compared. The only monetary savings that can be achieved are through a reduction of the energy costs in some of the cases with insulation, whereas all other costs are higher as a result of more insulating material used in the construction. Since the energy costs of the New Generation Office Building are only 5% of the total life cycle costs, the savings do not reduce these significantly.

# 1 New Generation Office Building

Farshad Nasrollahi

## 1.1 Introduction

The New Generation Office Building is one of three pilot projects designed within the Young Cities Research Project. The main objective of this pilot building was sustainability from an ecologic, economic and socio-cultural point of view. In this regard, ecological sustainability is achieved through energy-efficiency as well as the development of a $CO_2$-efficient design.

The secondary objective of the office building pilot project is to address cost efficiency. A decision was made to use cost-neutral methods which would have a minimum effect on the building costs, in contrast to cost-intensive measures. Less emphasis is put on construction and technology related fields; however, these matters are considered wherever applicable. Improvements to the internal thermal comfort as well as transparency, compared to existing office buildings in Iran, are further objectives considered in the pilot project, which also addresses socio-cultural sustainability.

Based on the main objectives, energy-efficiency and cost-efficiency, the New Generation Office Building's concept was designed by implementing passive architectural strategies—as the most reliable cost-neutral method—to reduce the heating, cooling and lighting energy demand of the building. The building form, orientation of the whole building as well as individual spaces, the window ratio of each orientation, the internal layout, etc. were designed according to extended climate studies and thermal analyses, with the aim of benefiting from the potentials of the climate and avoiding its negative impacts as much as possible. These studies have been used to investigate the effects of different architectural and constructional features on the energy performance of office buildings through energy simulations. DesignBuilder, as a dynamic energy simulation software tool (EnEf.co, 2013), is used for the simulations of the building within the basic studies regarding architectural energy efficiency. The studies identified the optimum amount or design for all architectural features to minimize the energy demand of office buildings (Nasrollahi, 2013-1).

The design of the building according to the results of these studies reduced effectively the energy demand of the New Generation Office pilot project solely by using an energy-efficient and optimized architectural design without increasing the building costs. Decisions concerning suitable shading devices, natural (and mechanical) ventilation, permitted airchange rate through infiltration etc. are based on the results of this research.

After minimizing the building's energy demand through the architectural design, constructional energy efficiency was the next area of research as this would help towards further reducing the building's energy consumption.

The pilot project is located in the south-west corner of the Shahre Javan Community in Hashtgerd New Town, Iran. The building will most probably be used by the Hashtgerd branch of the "New Town Development Corporation" (NTDC) and is therefore planned to match the special requirements of this organization; however, this office building is also planned with a higher degree of flexibility than a standard office building so that it can also be used by other institutions.

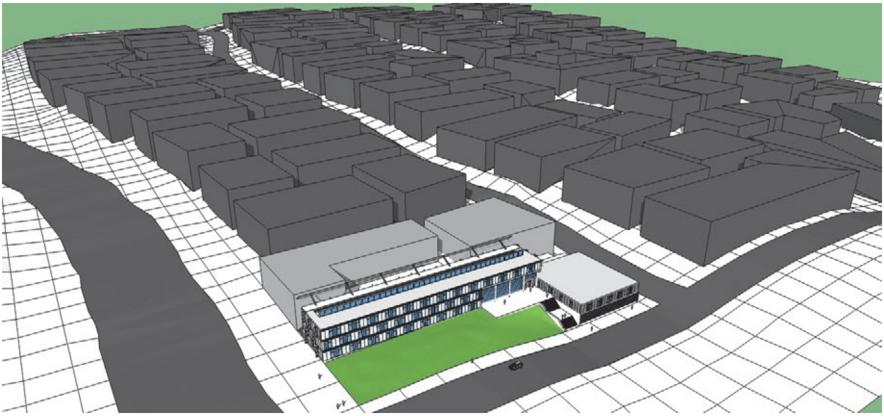


Fig. 1: View of the New Generation Office Building in the Shahre Javan Community

## 1.2 Optimum Urban and Building Form

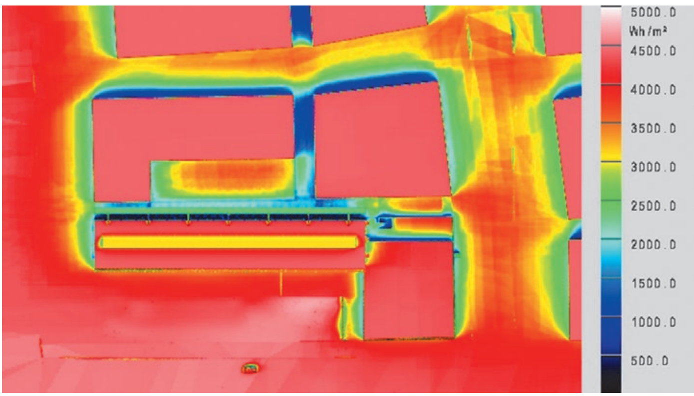



Fig. 2: Incident solar radiation on the outer surfaces of the commercial, mixed-use complex (Samimi and Nasrollahi, 2013)

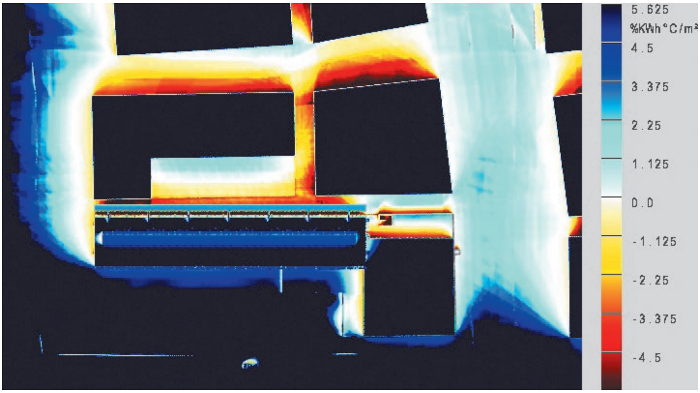



Fig. 3: Positive and negative effects of the solar radiation on the outer surfaces of the commercial, mixed-use complex (Samimi and Nasrollahi, 2013)

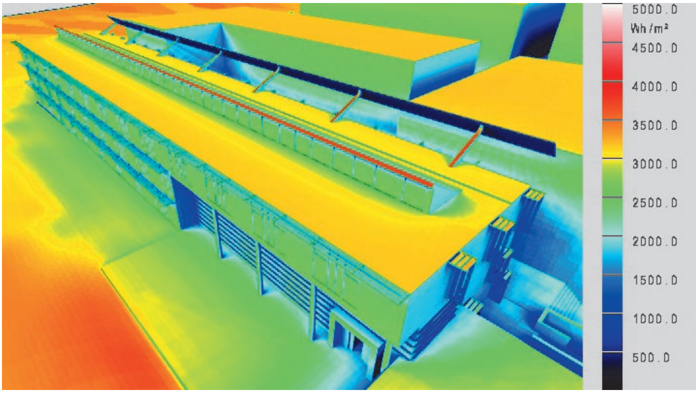



Fig. 4: Amount of incident solar radiation on the building envelope in winter (Samimi and Nasrollahi, 2013)

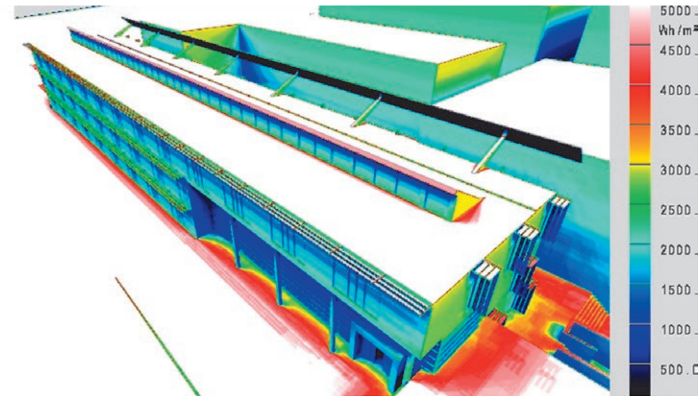



Fig. 5: Amount of incident solar radiation on the building envelope in summer (Samimi and Nasrollahi, 2013)

In order to achieve an optimized architectural design, the urban form of the neighborhood as well as the building form must be optimized. In this regard, several simulations are performed to identify the advantages and disadvantages of each surface according to the amount of solar radiation that is received during the heating and cooling periods.

### 1.3 Cross Natural Ventilation

The cooling energy demand of the New Generation Office Building is decreased by reducing the external heat gains through an optimum orientation and building form, an optimized window area as well as the application of shading devices. Because it is not possible to completely prevent external heat gains and because there are also considerable internal heat gains, the building must be cooled. Natural ventilation is an effective measure to reduce the cooling energy demand. Cross ventilation is much more effective than single-side ventilation. In order to further reduce the cooling energy demand in the New Generation Office Building, natural cross ventilation methods are used. To achieve cross ventilation, the ceilings in the corridors (circulation area), located between the south and north-facing offices, is lower so that the air can move freely from one side of the building to the other.

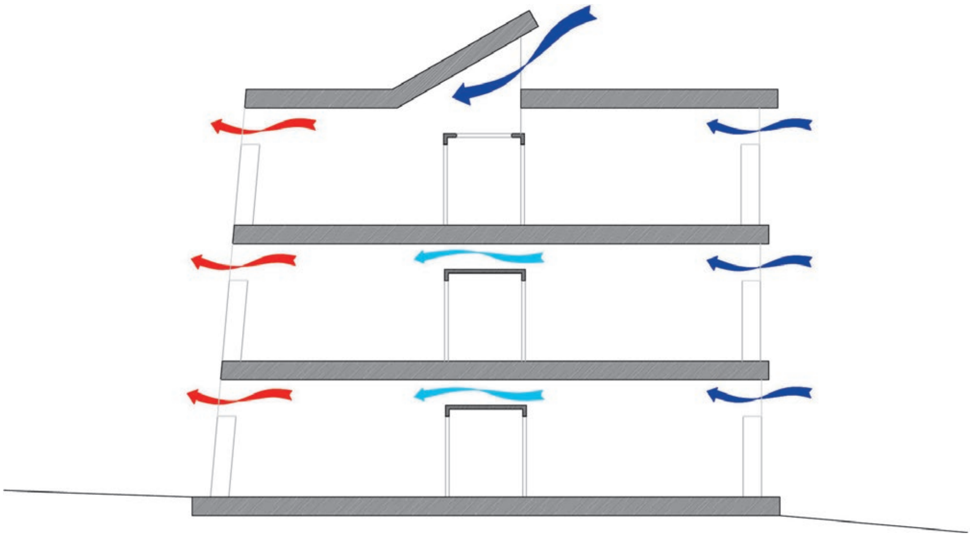


Fig. 6: Cross ventilation in the New Generation Office Building

## 1.4 Vertical skylights

Due to the fact that the heating energy demand of buildings in the climatic conditions of Hashtgerd New Town takes up a larger part of the total energy demand than the cooling energy demand, a reduction of the heating energy demand can help towards decreasing the total energy demand. The heating energy requirements of the New Generation Office Building can, for example, be decreased by increasing of the solar heat gains in winter. The south offices have sufficient solar heat gains through the south-facing windows, but the north offices have only very low solar heat gains in winter. Skylights that are located above the central corridor and the north-facing offices can increase the solar heat gains of these spaces and thus decrease the heating energy demand of the building. Horizontal or slightly inclined skylights receive more solar radiation in summer than in winter, which would lead to a further increase of the cooling energy demand. Vertical skylights, on the other hand, receive greater solar heat gain in winter and less in summer. This has the effect that the heating energy demand is decreased without increasing the cooling demand. In order to minimize the solar heat gains of the vertical skylights, the roof is extended so that it acts as an overhang. In the New Generation Office Building, vertical skylights are implemented above the central corridor and the north-facing offices on the second floor. This solution increases the solar heat gains and improves the penetration of daylight in these spaces; thus reducing both the heating and lighting energy demand.

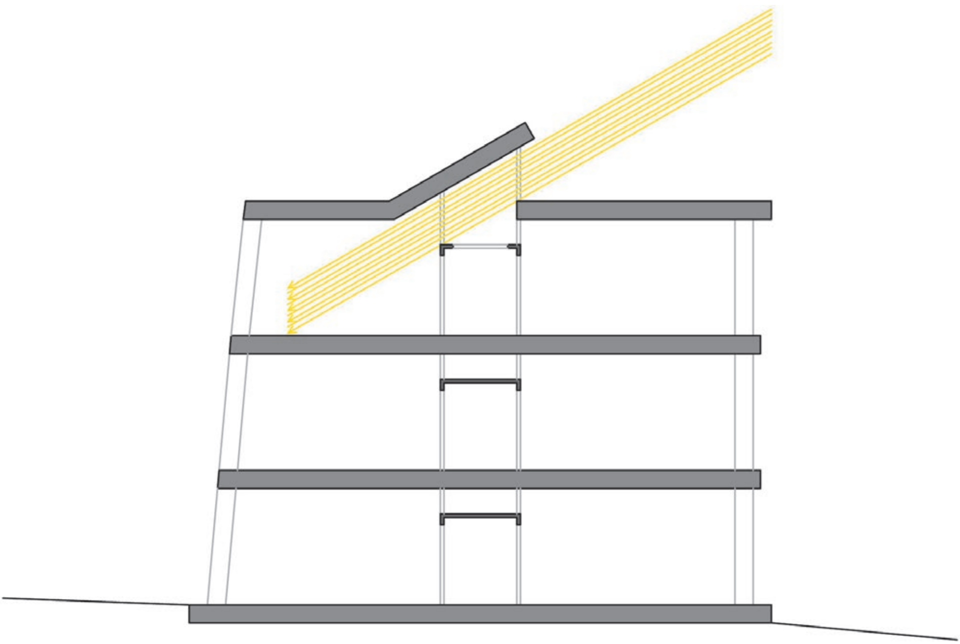


Fig. 7: Vertical skylight in the New Generation Office Building

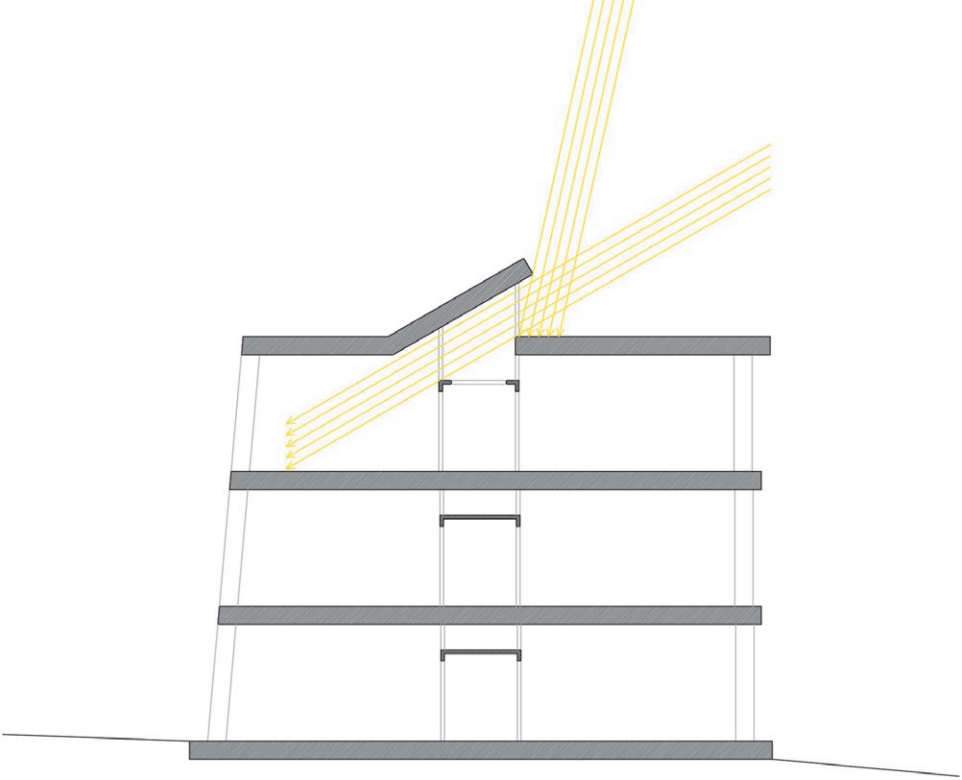
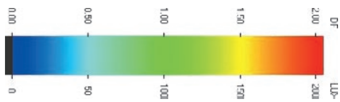


Fig. 8: Solar heat gains in winter and summer through the skylight of the New Generation Office Building

## 1.5 Daylight in the New Generation Office Building

The New Generation Office Building is not only energy efficient from a thermal point of view, it also features an efficient use of daylight in order to minimize the lighting energy demand. The window area of each façade is optimized based on a minimization of the total heating, cooling and lighting energy demand. The following figures illustrate the illuminance levels and daylight factors in the three floors of this building according to the sky model of a CIE overcast day (10,000 Lux) (see Figures 9–11).



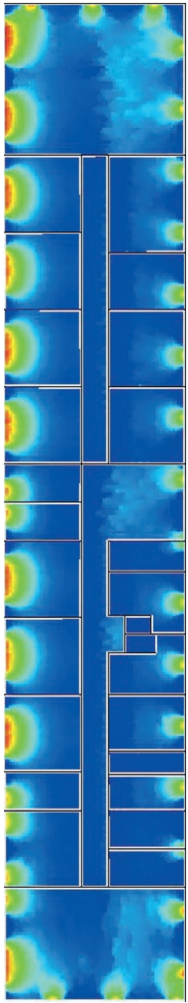



Fig. 11: Illuminance levels and daylight factors on the second floor

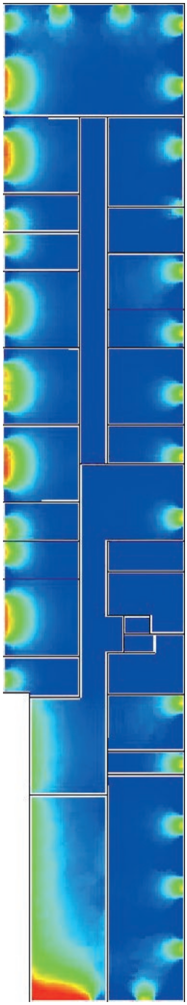


Fig. 10: Illuminance levels and daylight factors on the first floor

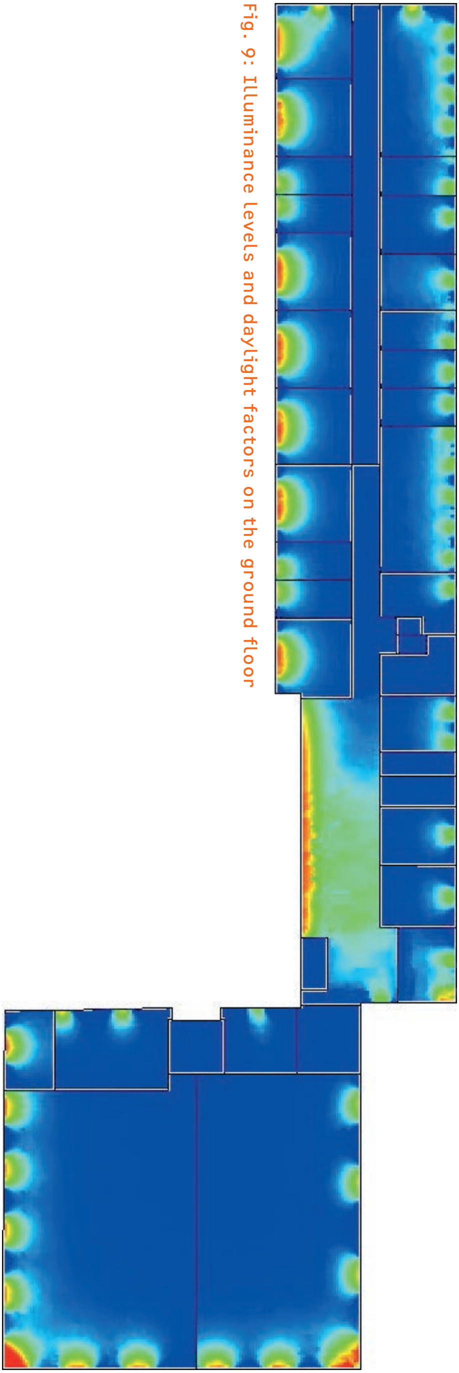


Fig. 9: Illuminance levels and daylight factors on the ground floor

## 1.6 Flexible Architecture

One of the concepts applied in the New Generation Office Building is flexible architecture to improve the adaptability and perform conversions more easily. All partition walls within the New Generation Office Building are designed using panels that can be exchanged and replaced easily. Due to the flexible partitions, the spatial organization of the building is flexible and can be adjusted at low cost and in a short period of time. The building can adapt quickly to new usages that may occur over time or become necessary within the existing office structure due to more flexible, modern working habits (such as changing teams).

This flexibility is especially important for the New Generation Office Building. The Hashtgerd New Town Development Corporation will be the user of this building; however, the corporation does not plan to stay in Hashtgerd permanently; then the building will be assigned to a new usage.

The flexibility of the floor plans and the possibility to make spatial changes enable the building's current and future users to adapt the inner structure and meet individual needs. This is an advantage for NTDC as well as for any other administrative organization or company that might use the building in future.

In addition, flexible architecture better meets the changing needs of employees. A quick reassembly of the walls allows for an optimal organization of the working teams. Compared to common gypsum plasterboard walls, the investment costs for the flexible wall system are higher. However, over the lifetime of the building, no large investments are necessary due to the flexibility of the wall panels. The additional advantages of the flexible architecture are the fast adaptation to the changing needs of employees, an increased capacity for conversion and the simplicity.

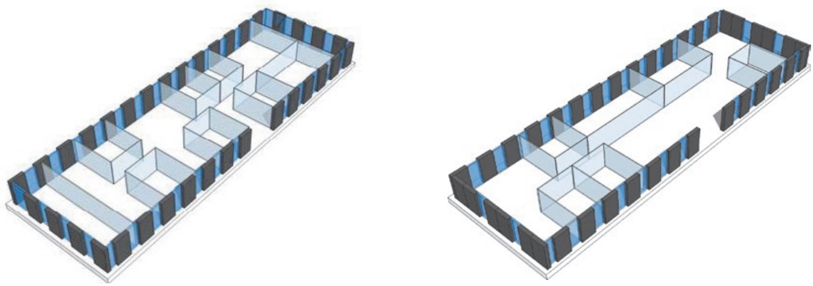


Fig. 12+13: Flexibility of the interior arrangement in the New Generation Office Building

## 1.7 Modular Architecture

The New Generation Office Building consists of modular components which enable a fast and simple assembly. This building incorporates the concept of modularity from the first planning and design stage onwards. The concept of modularity affects the building's spatial distribution and interior zoning; it influences the floor plans, the façades as well as various other building elements.

A high building quality is achieved through modular architecture since it enables the use of identical elements with the same shapes and dimensions. A modular system decreases the complexity of construction as well as the building costs. Furthermore, it is possible to work with prefabricated components, which are beneficial when it comes to the assembly on site.

Modular designs and the use of modules for architectural and constructional designs increase the flexibility of the building. They reduce the complexity and the costs for the planning and development of the building and its structure. Modular designs also increase the transferability of the building concept to other regions. The construction of modular architecture is cost and energy-efficient, simply because construction is faster. Compared to a common construction system, the investment costs for the modular architecture are lower. In addition, there are less on-site construction problems and defects, which eventually leads to higher quality.

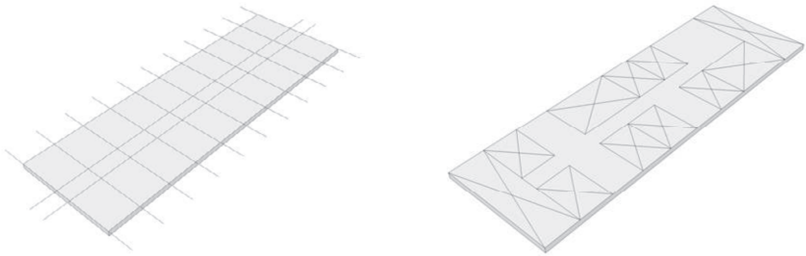


Fig. 14: Modular grid at the first planning and design stages & the effect of the modular grid on the space distribution and building zoning

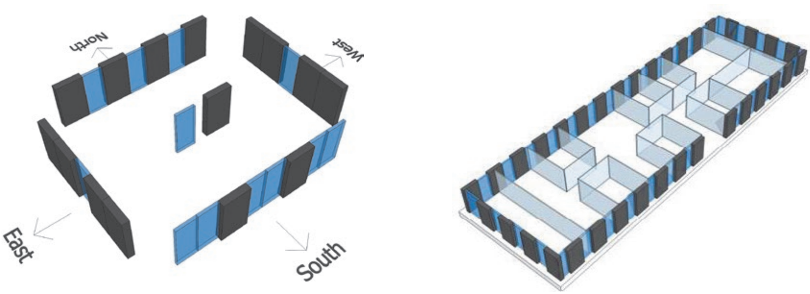



Fig. 15+16: Modular design both in the building design (plan) and the building elements (façade)

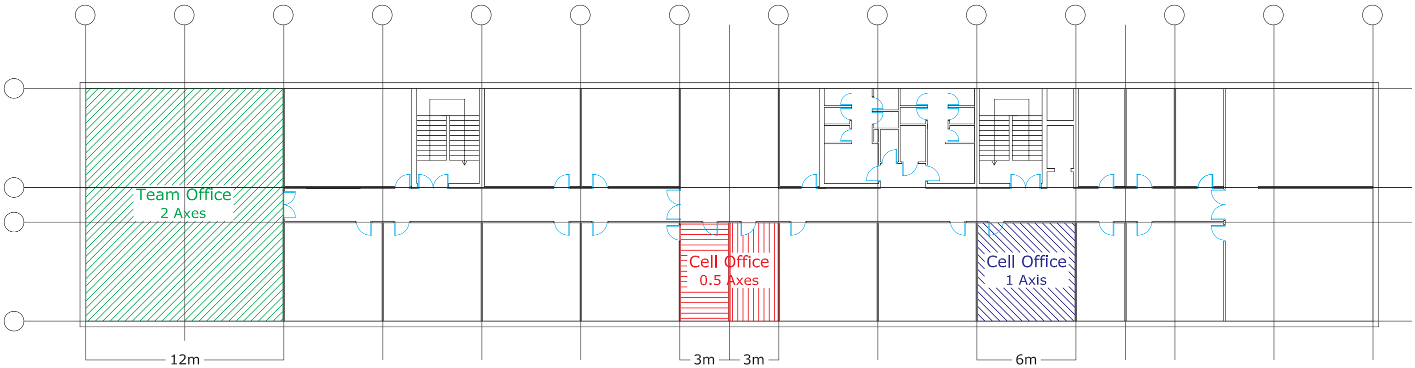



Fig. 17: Arrangement of offices using a modular design for the New Generation Office Building

## 1.8 Architectural Design

The preliminary design of the New Generation Office Building is developed based on the results of research regarding energy efficiency and a room schedule. The preliminary design is evaluated from an energy as well as cost efficiency point of view and further developed up until reaching the final design. Two main design alternatives are investigated for the New Generation Office Building. The first one is presented here in this paper. The second is a further development of the first including some new alternative energy saving concepts (for more information refer to Nasrollahi, 2013-2).

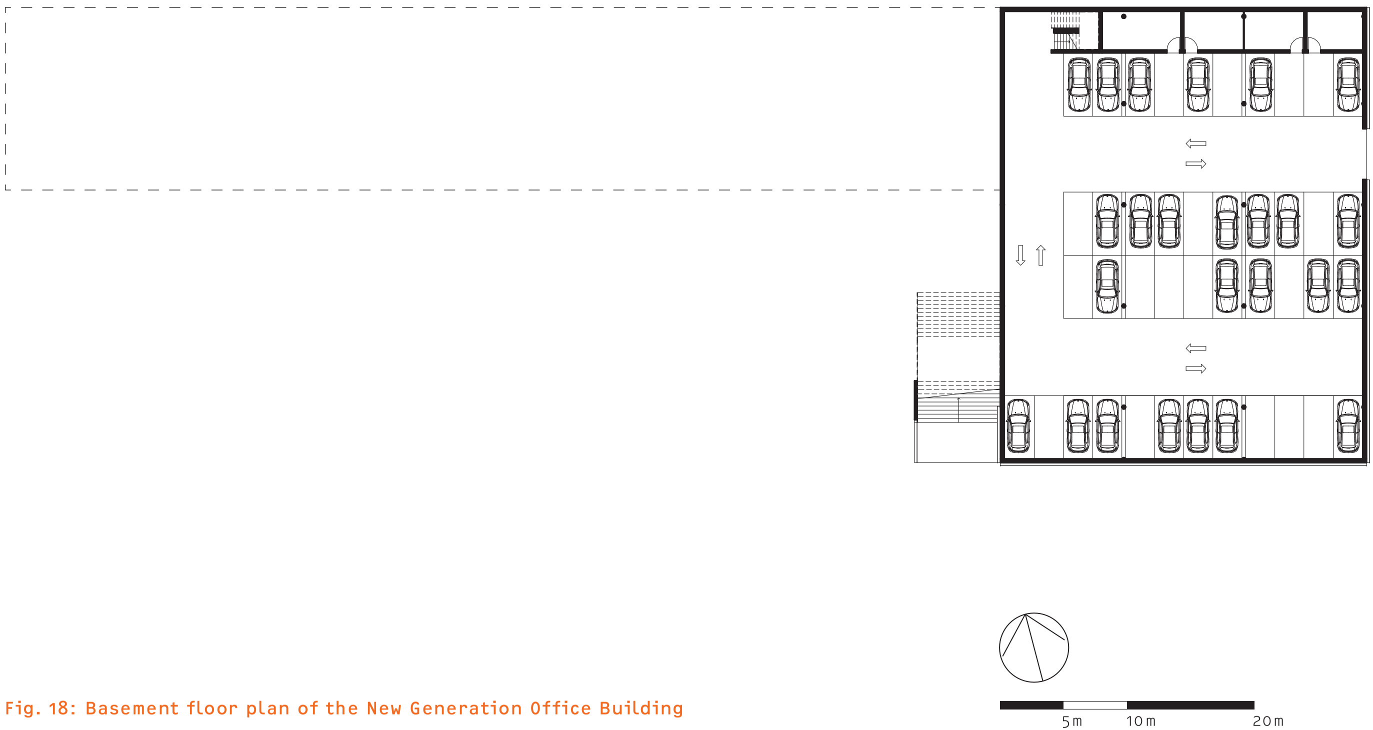



Fig. 18: Basement floor plan of the New Generation Office Building

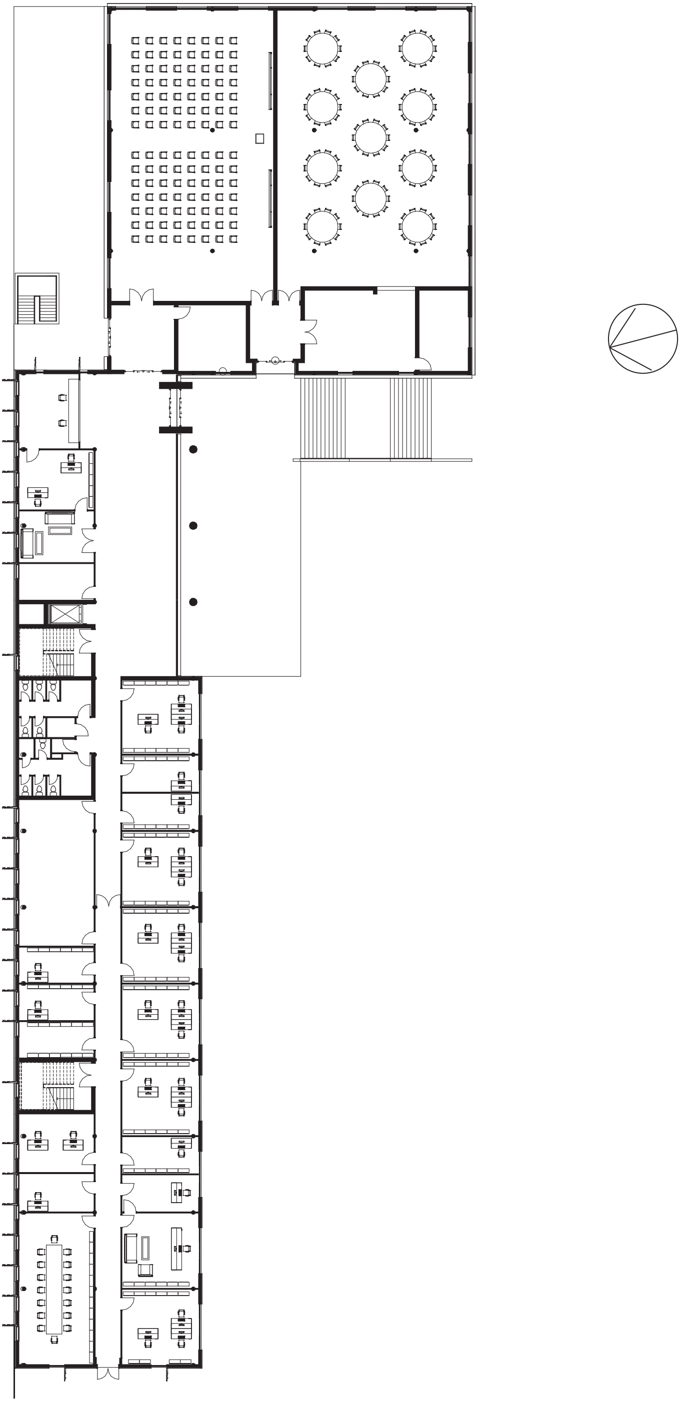



Fig. 19: Ground floor plan of the New Generation Office Building

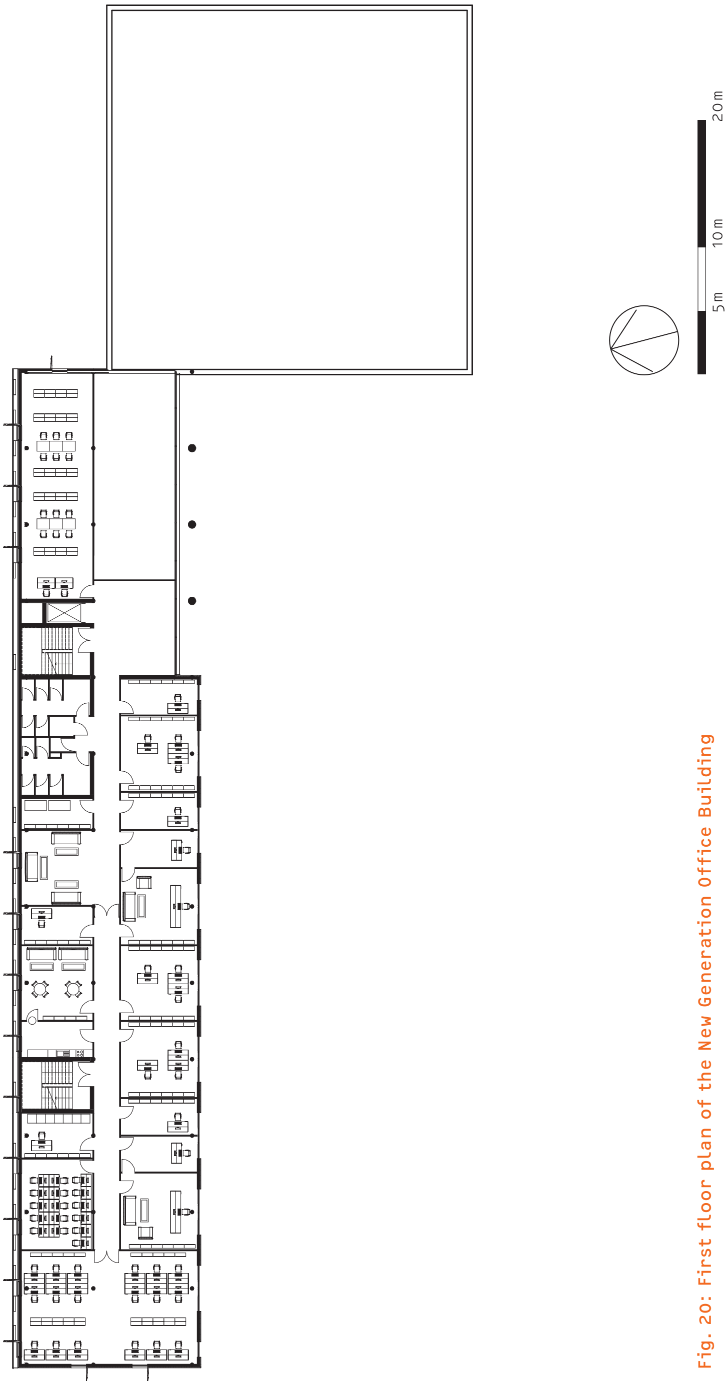



Fig. 20: First floor plan of the New Generation Office Building

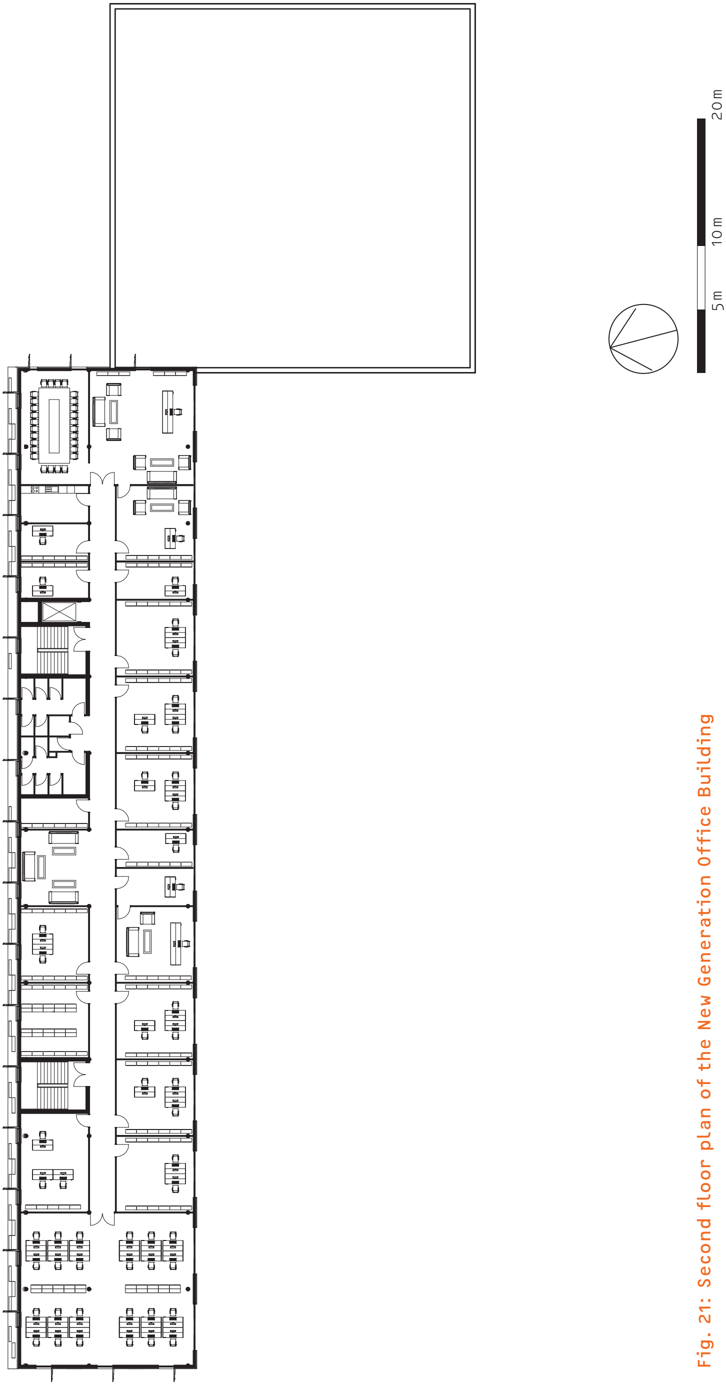
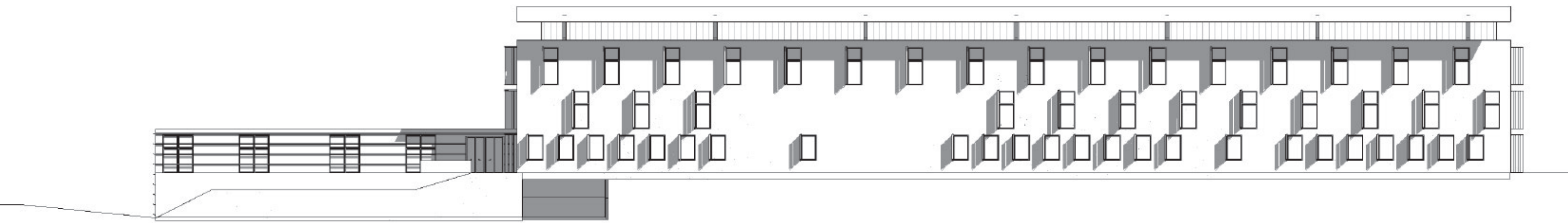



Fig. 21: Second floor plan of the New Generation Office Building

Fig. 22: South elevation of the New Generation Office Building



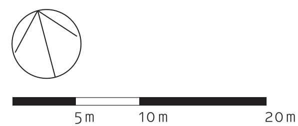



Fig. 23: North elevation of the New Generation Office Building

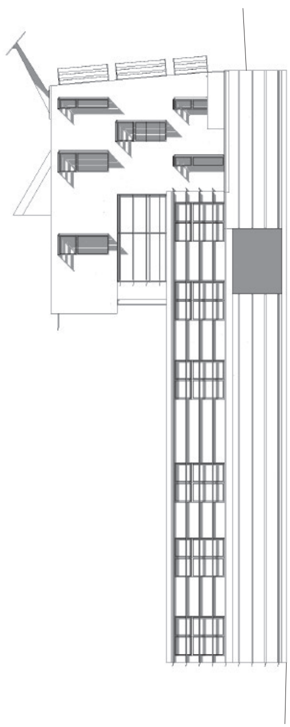


Fig. 24: East elevation of the New Generation Office Building

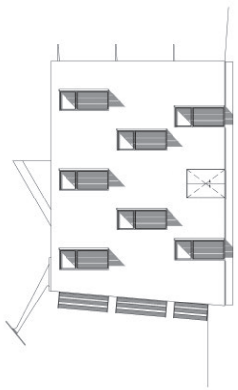
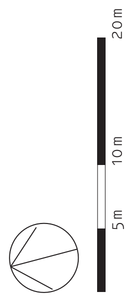


Fig. 25: West elevation of the New Generation Office Building



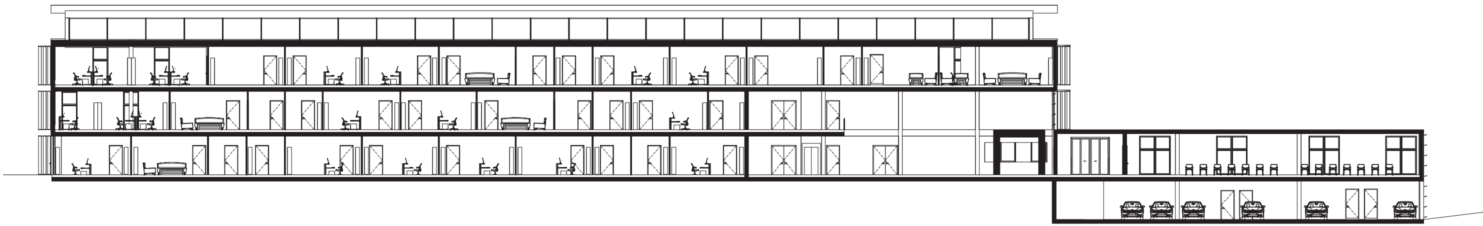
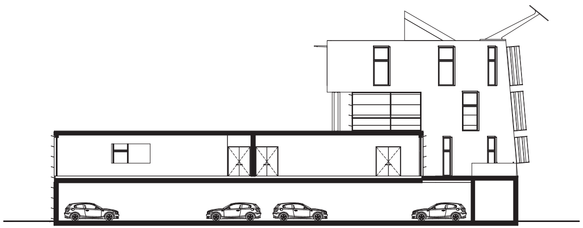


Fig. 26: East-west section of the New Generation Office Building



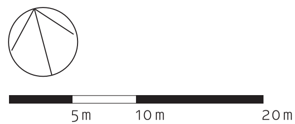



Fig. 27: North-south section of of New Generation Office Building

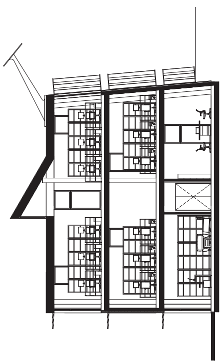


Fig. 28: North-south section of New Generation Office Building

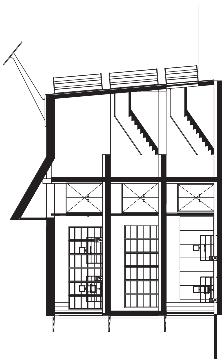
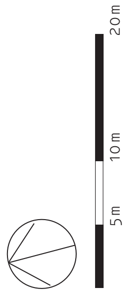


Fig. 29: North-south section of New Generation Office Building



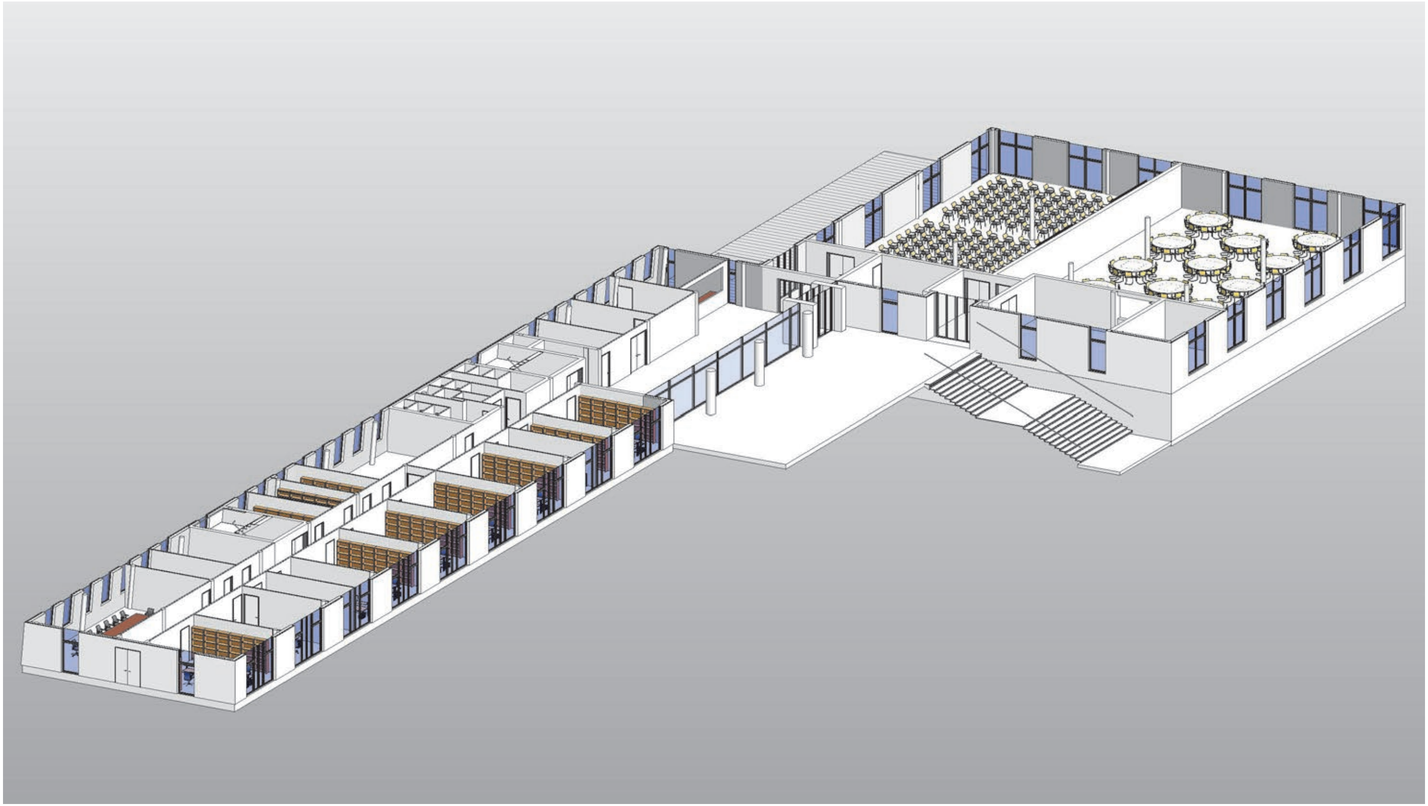


Fig. 30: Axonometric view of the New Generation Office Building's ground floor

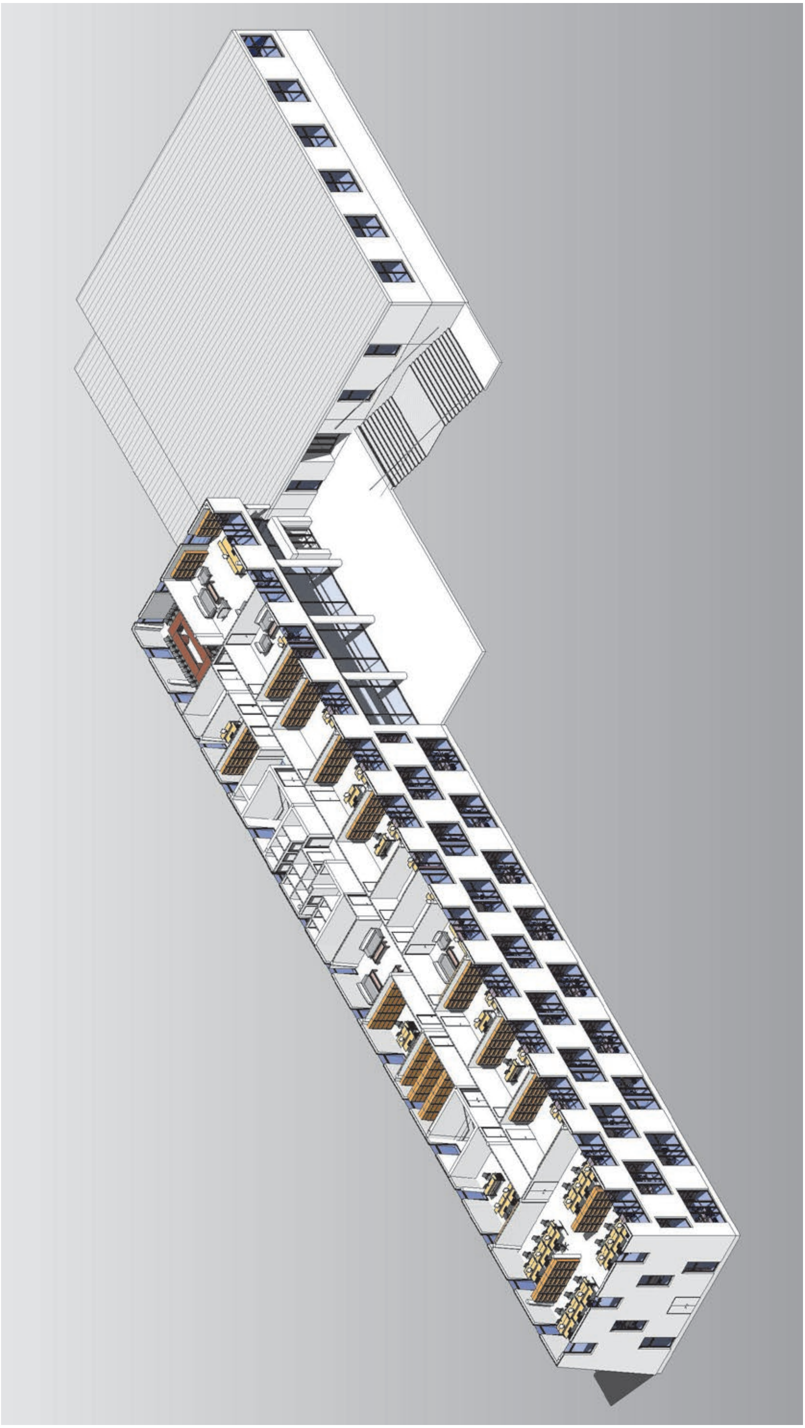


Fig. 31: Axonometric view of the New Generation Office Building's second floor

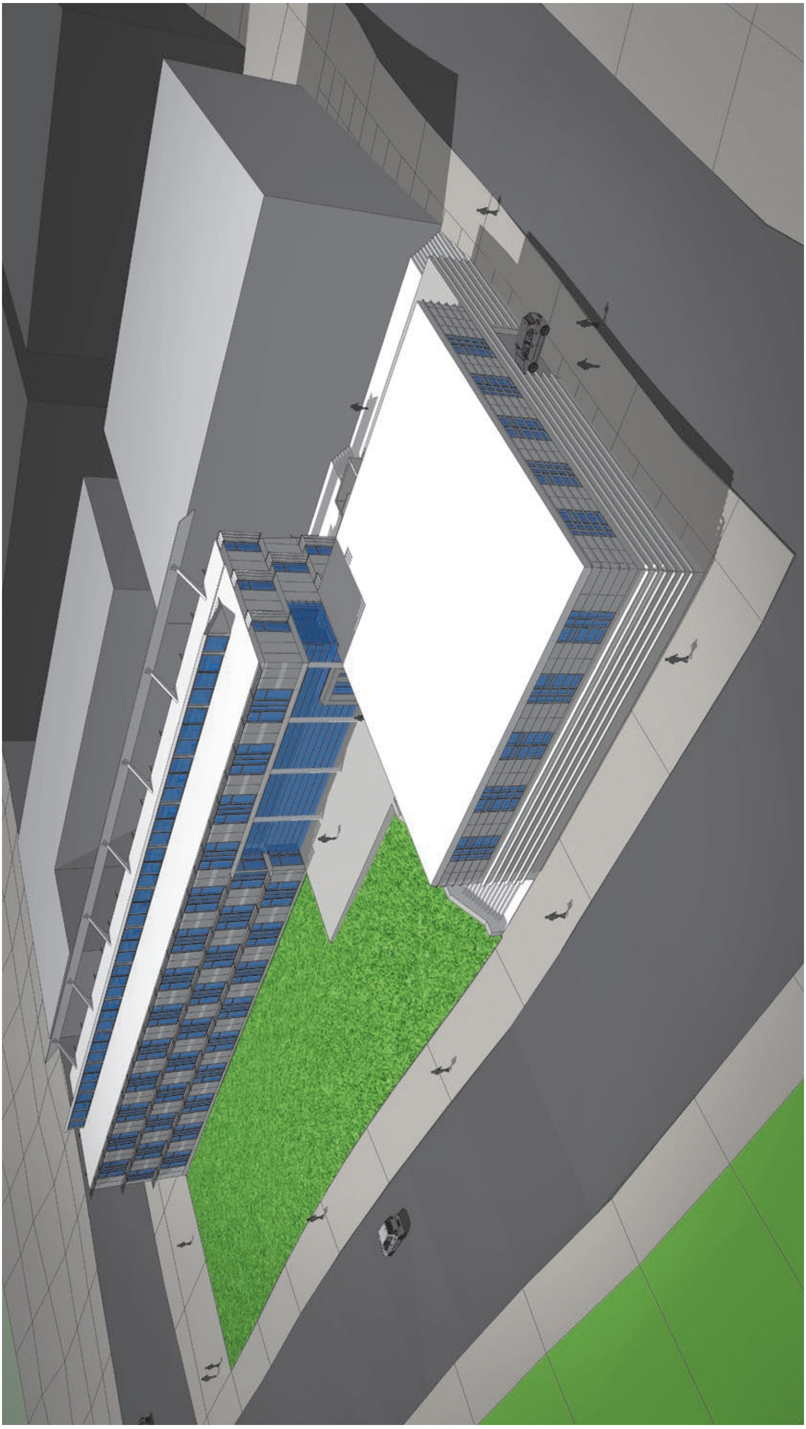


Fig. 32: South-east view of the New Generation Office Building

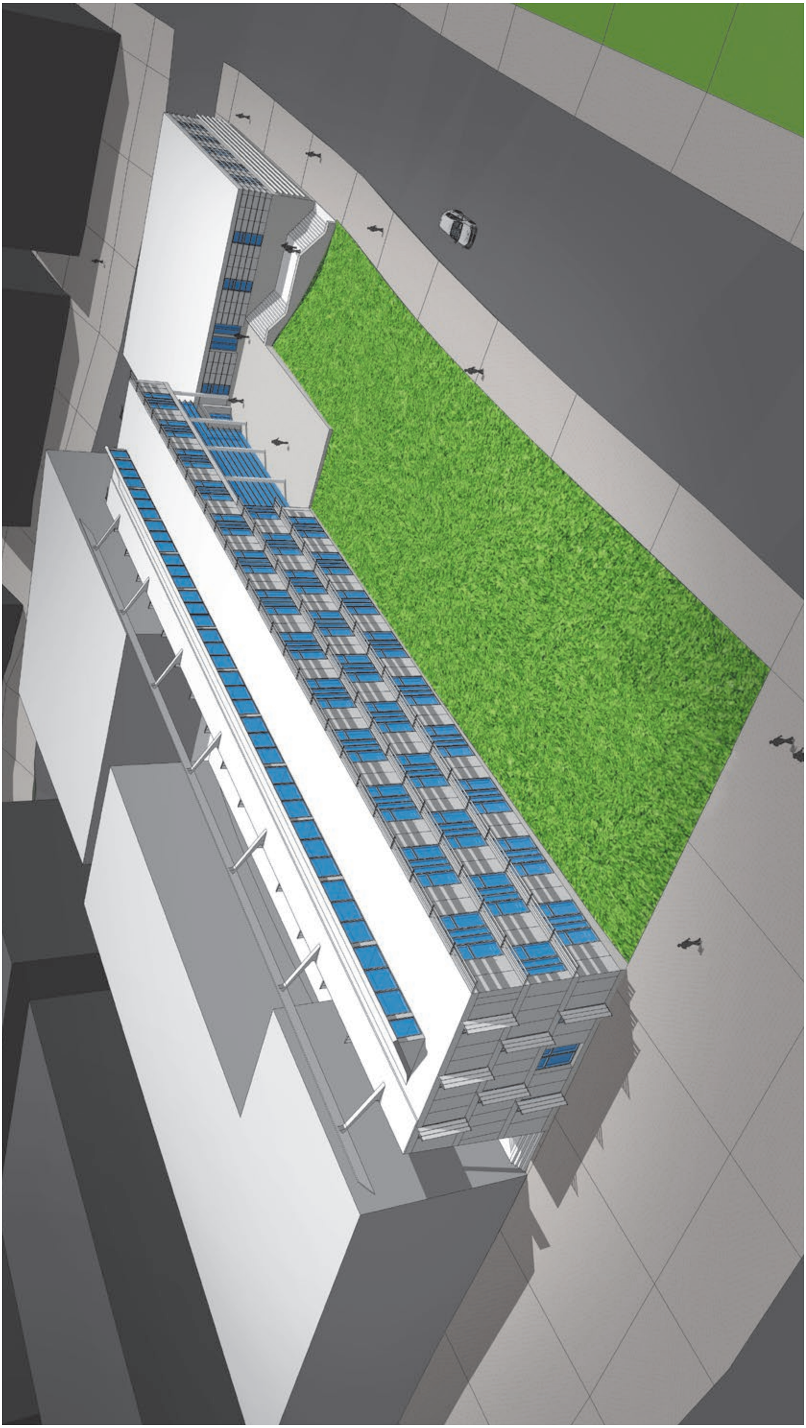


Fig. 33: South-west view of the New Generation Office Building

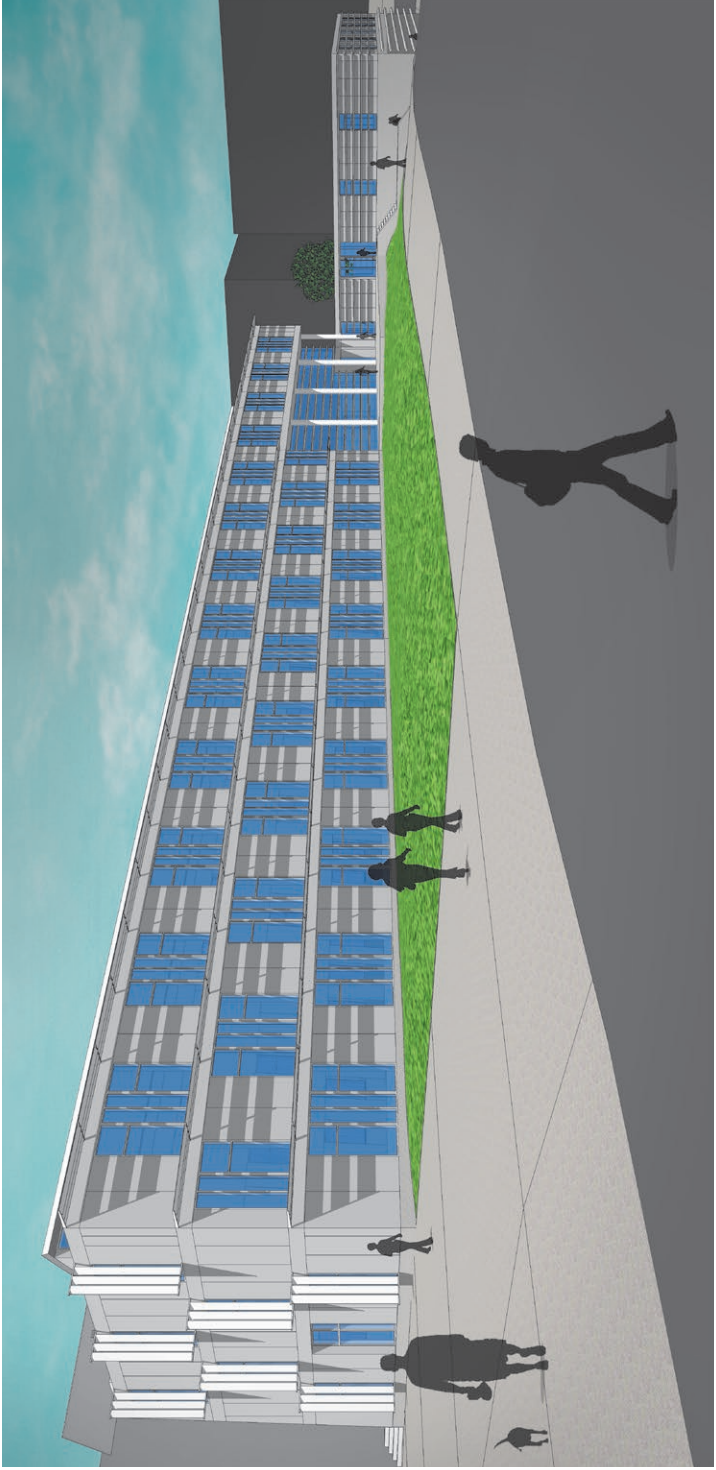


Fig. 34: South-west view of the New Generation Office Building

Fig. 35: South view of the New Generation Office Building

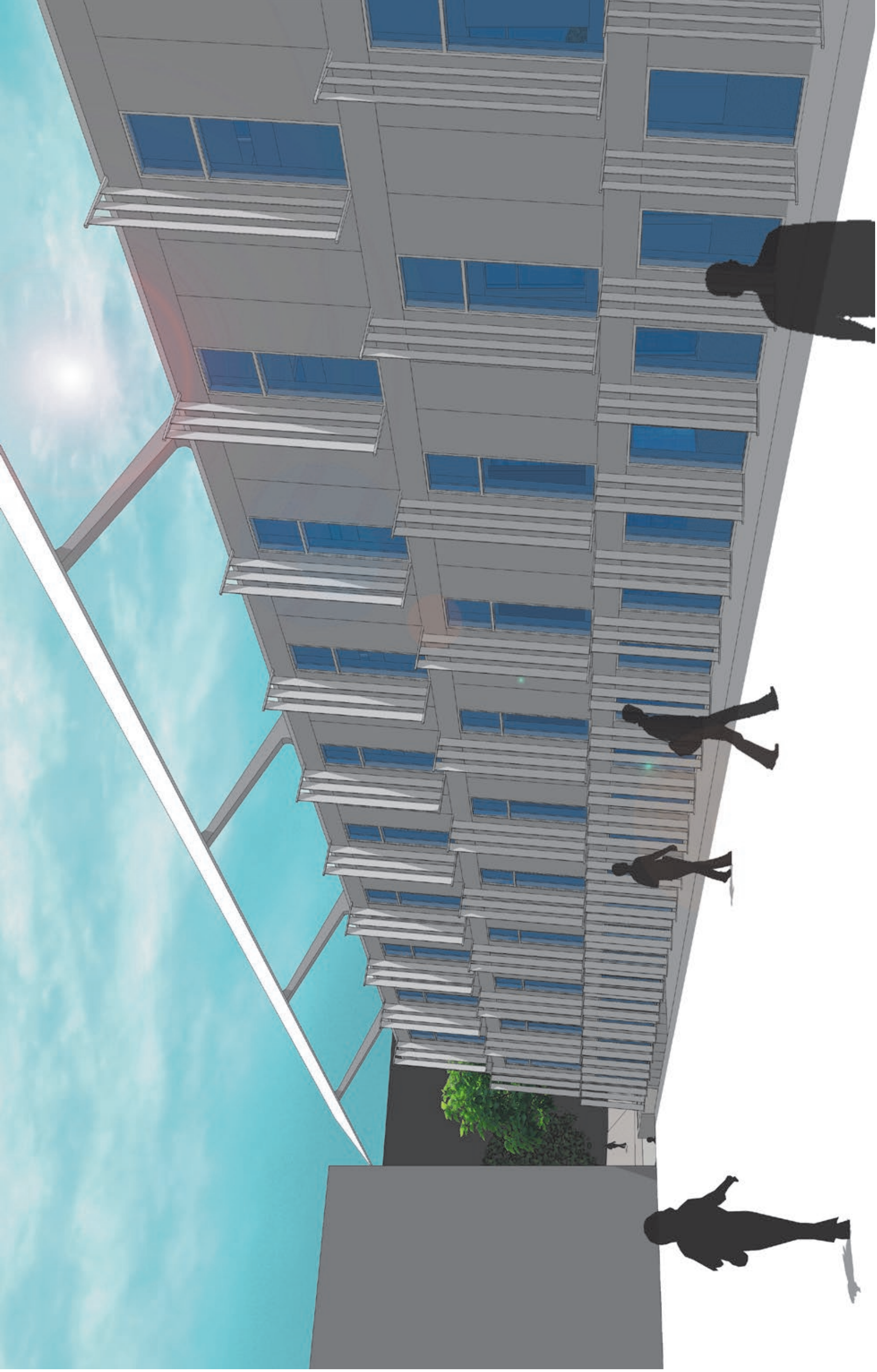


Fig. 36: View of the shading devices in the north façade

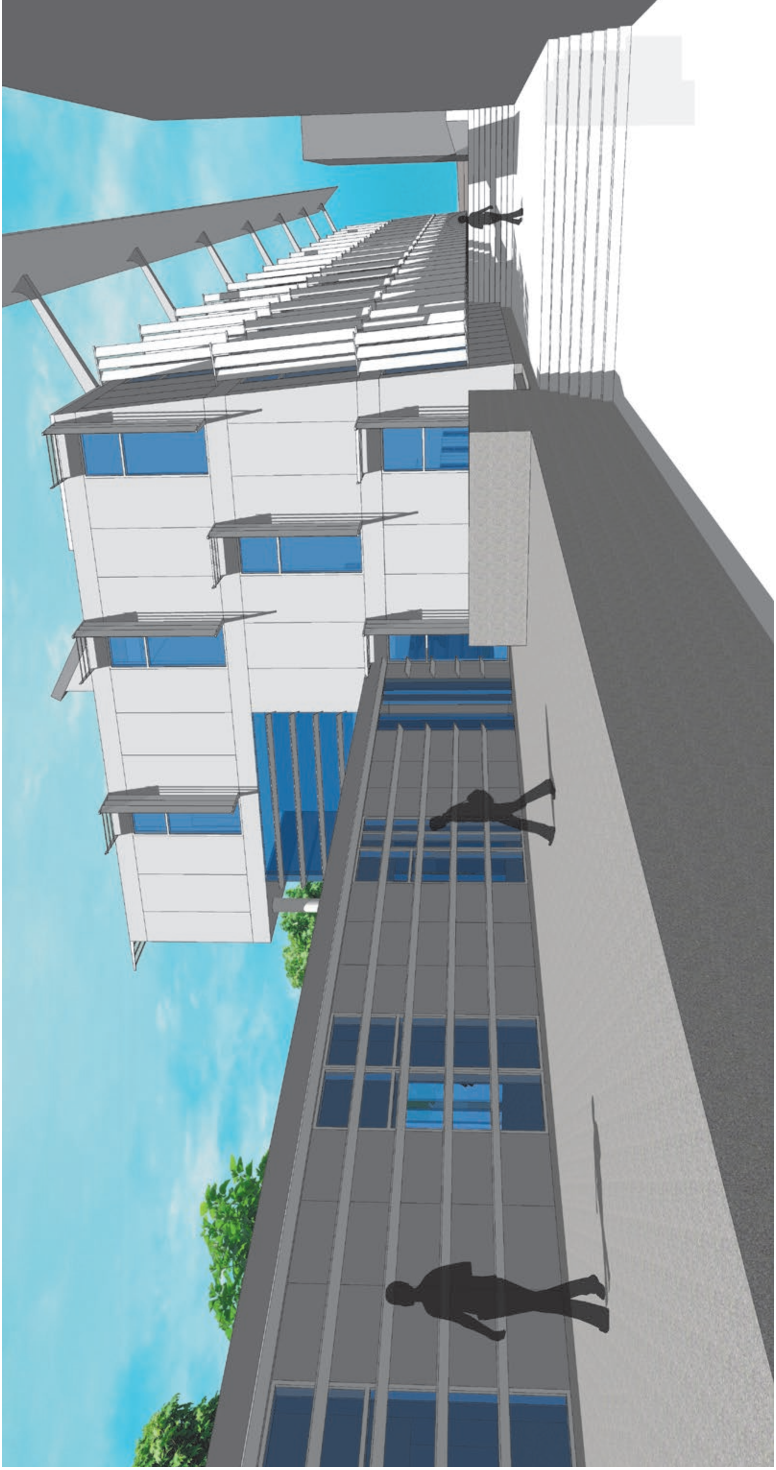


Fig. 37: East view of the New Generation Office Building

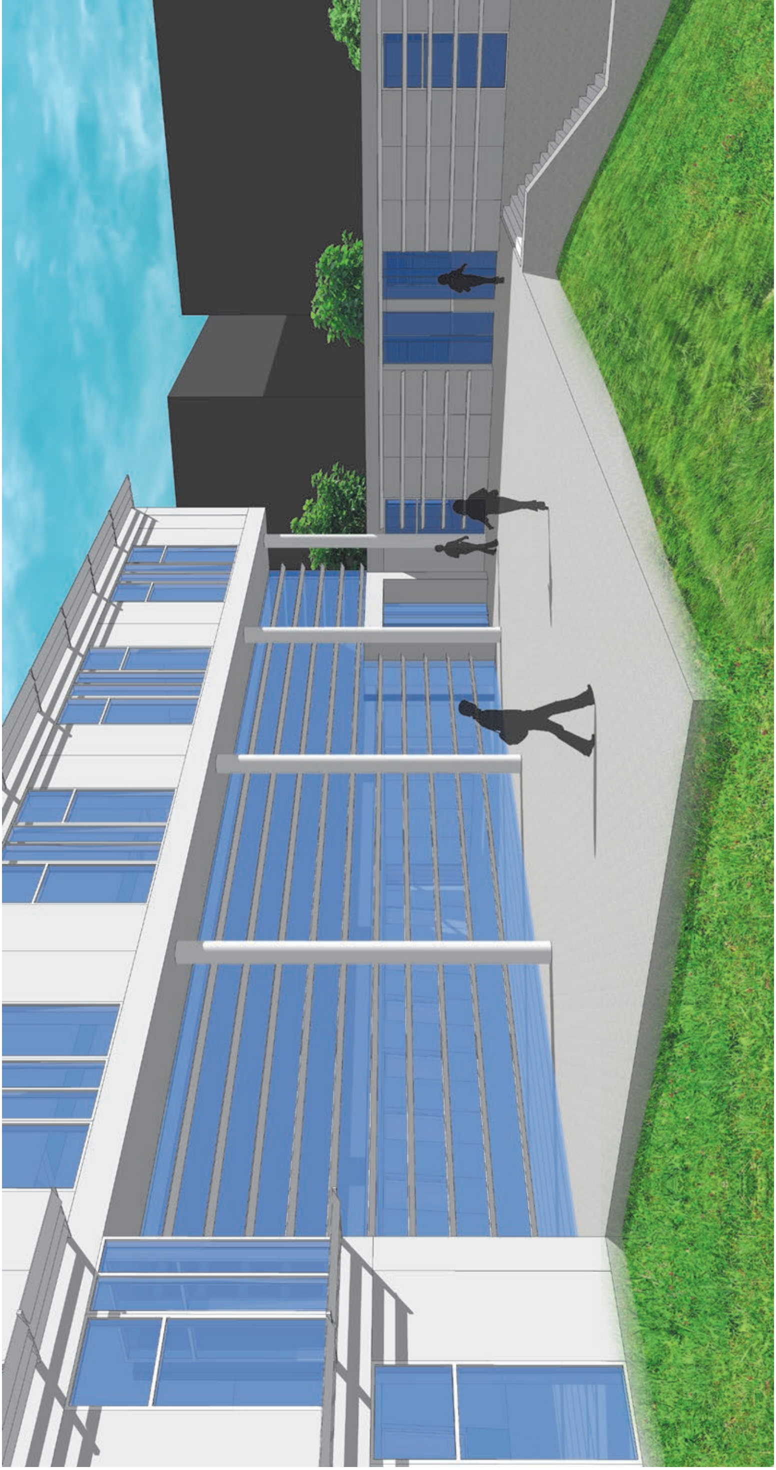


Fig. 38: View of the entrance

# 2 Optimum U-values for the Thermal Envelope of the New Generation Office Building

Masoudeh Nooraei | Farshad Nasrollahi

## 2.1 Importance and aim of research

In addition to the skin of the human body and the clothes covering it, the envelope of the building is the third layer protecting the human body from the effects of the outdoor climate. The building envelope is where the building is connected to the outdoors and the heat transfer between the inside and outside takes place. Thus, it plays an essential role in the building's thermal performance and has a substantial effect on its users' well-being as well as on the energy bills.

In office buildings, the effect of the envelope specifications on the thermal behavior of the building is even more critical. The reason is that these buildings require more illuminated indoor space, and thus a more transparent envelope. This makes the building more sensitive to the outdoor climatic conditions compared to buildings with different functions. Therefore, there is greater need to examine the envelope in terms of its thermal properties.

Considering all of the facts mentioned above, the aim of this research is to study the potential monetary and energy savings through the use of thermal insulation in external walls, roofs and floors (ground and exposed) in the New Generation Office Building in the warm and dry climatic conditions of Hashtgerd New Town. The aim is to optimize the U-value of the envelope's opaque elements in order to enhance the thermal performance of the office building and its occupants' comfort during both the heating and cooling periods and save money on energy bills.

## 2.2 Overview of research

The research is at first focused on the energy consumption of the New Generation Office Building and the degree of reduction as a result of adding thermal insulation to the building envelope. The heating and cooling energy demands are considered separately in this process since they are, on the one hand, not affected in the same way and are, on the other hand, met by different energy sources—gas and electricity respectively—that result in different primary energy and carbon emission values. The optimum case, in consideration of the total1 energy consumption, will be determined at the end.

Thermal performance simulations of the New Generation Office Building with different thermal resistance values of the envelope are undertaken using the dynamic thermal simulator EDSL TAS free trial version 9.2.1

with the hourly climatic data from the Hashtgerd weather file, the same that has been used in all the Young Cities Project research up until now. The TAS dynamic simulation model calculates the heating and cooling loads by taking the thermal properties of materials as well as the energy exchange process between interior and exterior into account. A detailed description of the procedure and assumptions applied in the simulated models of this research can be found in the TAS theory manual.

The base model for thermal simulations is defined according to the results obtained from the research that has already been performed for the New Generation Office Building in the Young Cities Project. The materials for the base model are defined according to the typical construction of office buildings in Iran. The only variable factor in the simulated models is the thermal resistance of the building envelope.

In the next step, different cases from the previous part of the study are analyzed from the point of view of associated costs. In this way, the initial costs, maintenance costs, energy and life cycle costs are calculated and studied for a 15-year period. The inflation rate, the real discount rate as well as the real price escalation rate are considered in the cost calculation to provide a clear view of the investment in the building energy sector.

## 2.3 Effect of thermal insulation on the energy demand of the New Generation Office Building

In this part of the study, the thermal behavior of the New Generation Office Building is simulated with construction specifications and occupancy patterns featured in Iranian offices using the free trial of EDSL TAS version 9.2.1. Nine case studies were examined to explore the effect that thermal insulation has on the building's energy consumption.

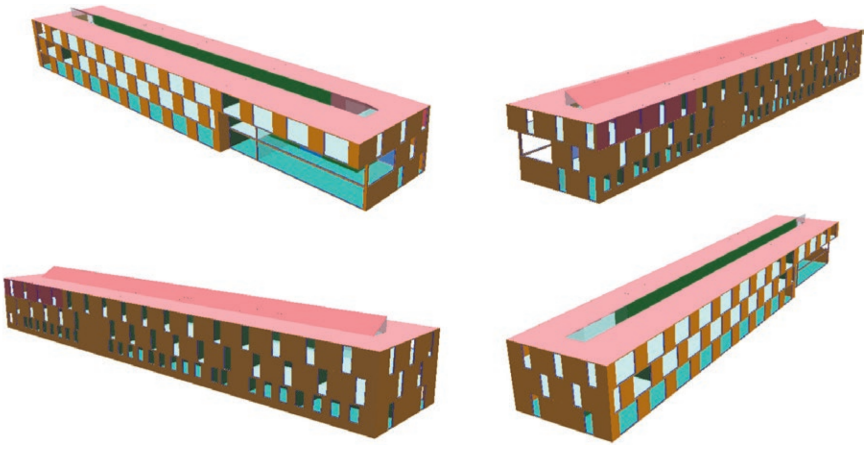


Fig. 39: 3-D geometric TAS model; South-east view (above left), north-east view (above right), north-west view (below left), and south-west view (below right)

### Thermal simulation modeling

At first, the energy consumption of the New Generation Office Building is established with various amounts of thermal insulation. Then, the building is modeled using the free trial version of the dynamic simulator EDSL TAS, version 9.2.1 (Figure 39).

The 3D geometric models of the building are based on architectural drawings. It is a simplified version of the original design ignoring the parking area and the sloped terrain to avoid complexities in the model and minimize the possibilities of inaccurate simulations. All building specifications—including the orientation and window ratios—are in line with the final design. Table 1 shows the geometric specifications of the simulation model.

| | | |
|---|---|---|
| **Floor area** | | 3,221 m² |
| **Volume** | | 9,824 m³ |
| **Window/floor ratio** | | 27% |
| | South | 19% |
| | North | 6% |
| | East | 1% |
| | West | 1% |

Tab. 1: Geometric specifications of the simulation model

The thermal performance of the building was simulated using the TAS Building Simulator as a calculation tool (EDSL TAS version 9.2.1 tutorial, 2011) with the following information:

- *Building summary:* The terrain type of the model is considered to be "town" with a 5-meter mean height of the surroundings (Figure 40).
- *Calendar:* The calendar created for the simulation is based on a Persian calendar, with Thursday and Friday as weekend, and including public holidays (Figure 41).
- *Weather file:* The building simulation takes the climatic conditions into account, including hourly variations in air temperature, humidity, solar radiation, wind speed and direction for a whole year. It goes without saying that weather stations closest to the building site provide the most accurate information. However, since there is no weather station in the Hashtgerd, the weather data file used in the TAS simulations is a file created on the basis of interpolated weather data (except solar radiation) from a couple of weather stations near the town filed in the Iran Meteorological Organization archive for a period of 21 years, from 1985 to 2006. The average of the available data is used to create the weather file. Solar radiation is taken from Meteonorm 6 for the Mehrabad station in Tehran since no other reliable information in this regard was found. This file appeared to be the best available at the time of starting the thermal modeling, but it may be improved for later studies.

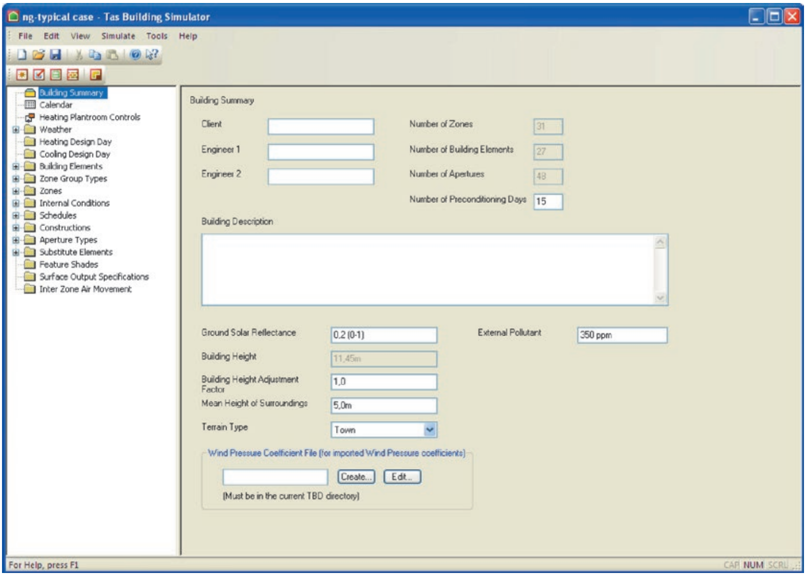



Fig. 40: Screenshot of the building summary

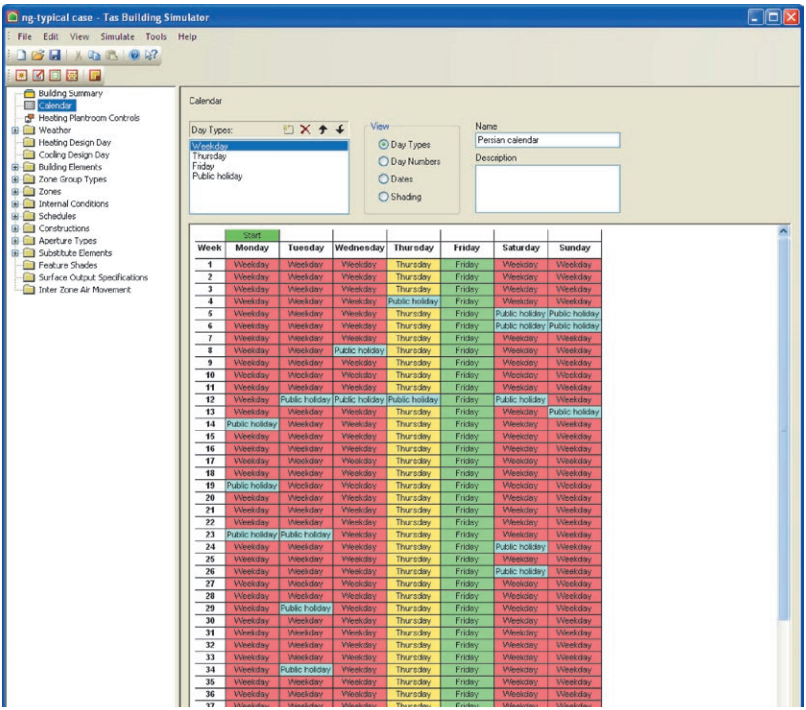



Fig. 41: Screenshot of the calendar

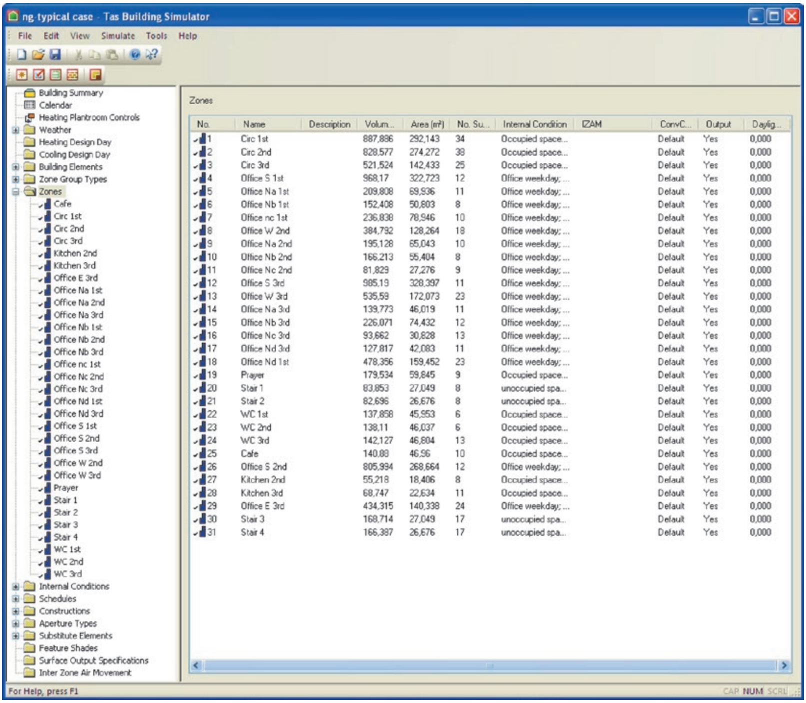



Fig. 42: Screenshot of the created zones

- *Zones:* A total number of 31 zones have been created in the simulation model which differ according to the activity (internal conditions) or the access to daylight (through windows) (Figure 42).
- Internal conditions: The internal conditions of each zone required the following input data:
  - *Infiltration:* The air infiltration rate is set at 0.7 ac/h for all zones. This value will certainly be kept as low as possible in the development of the pilot project: But in the case of the simulating model, it was agreed that 0.7 ac/h is a figure that can easily be achieved on the Iranian building market.
  - *Ventilation:* The ventilation rate is calculated for each zone in consideration of the number of occupants and the level of pollutants inside the space. In most zones, this number is zero since infiltration provides the required amount of fresh air.
  - *Lighting gain:* The target illuminance set for each zone is based on the activity taking place there, as follows:
    Office and work space: 500 lux
    Prayer room: 300 lux
    Circulation, kitchen and café: 200 lux
    WC: 100 lux

If the illuminance level is lower than the target illuminance, the light gain is at its maximum. The light gain decreases linearly as the illuminance level increases until the illuminance is as high as the target illuminance or greater, at which point the light gain is zero.
- *Occupancy heat gain:* Both sensible and latent heat gains are calculated according to the number of occupants in each zone and their activities (according to Szokolay, 2004). A total of 122 persons occupy the building, working from 8 am to 4 pm on weekdays.
- *Equipment heat gain:* 61 computers and 15 printers are assumed to be inside the office zones. Both the equipment sensible and latent heat gains are calculated for each zone separately (according to Szokolay, 2004).
- *Thermostat:* The upper comfort limit in summer and the lower comfort limit in winter are set at 27°C and 21°C respectively in all areas. These levels were chosen according to the ANSI/ASHRAE Standard 55, Page 5 (2004). In other words, the mechanical cooling systems in the building start up as soon as the inside temperature exceeds 27°C. Similarly, the heating system is on at internal temperatures lower than 21°C. A set-back value of 12°C was considered for the heating system to prevent the internal building temperature from falling below this value and to avoid very low temperatures in the building. Both the heating and cooling systems are set to work from 7 am to 4 pm in office zones and during the working hours of other zones on weekdays if required. The systems are off on weekends and public holidays.

- *Construction:* As shown in table 2, the construction layers of each building element are defined according to typical construction styles of office buildings in Iran. The intention has been to only differ between the thermal insulation and windows in the various cases. This method facilitates the comparison, especially later in the cost analysis.
  - *Thermal insulation:* Planners and constructors are requested to use materials with very low (less than 0.04 W/m°K) thermal conductivity values to improve the building's energy performance. Different types of insulating materials are available on the Iranian building market. The most common are inorganic fibrous materials, such as glass wool and rock wool, and organic foams, expanded and extruded polystyrene, as well as polyurethane.
    Table 3 (Papadopoulos, Karamanos and Avgelis, n.d. & Knauf insulation, n.d. & Strategic Planning and Monitoring organization, 2009) shows a comparison between these options from different viewpoints.
    According to this table, the advantages of glass mineral wool outweigh the others'. Nevertheless, for financial reasons, polystyrene was chosen for this project. Since the building only has three stories, combustibility is not a critical issue. The thickness of the thermal insulation as well as the glazing and frames differ in the case studies and are therefore not defined in table 2.

| Building element | Material | Thickness (mm) |
|---|---|---|
| **External wall** | (Interior) plaster | 30 |
| | PFA concrete block | 150 |
| | Expanded polystyrene board | |
| | Cement render | 50 |
| **Internal wall** | Fiber board panels | 50 |
| **Ceiling** | Concrete (underside) | 250 |
| | Air cavity | 100 |
| | Slate tile | 50 |
| **Roof** | Concrete (underside) | 150 |
| | Expanded polystyrene board | |
| | Foamed blast furnace aggregate | 50 |
| | Lightweight concrete | 10 |
| | Asphalt | 5 |
| | Slate tile | 50 |
| **Ground floor** | Slate tile (topside) | 30 |
| | Expanded polystyrene board | |
| | Concrete | 100 |
| | Sand and gravel aggregate, oven dried | 50 |
| | Clay (ignored in U-value) | 1,000 |
| **Exposed floor** | Slate tile (topside) | 50 |
| | Air cavity | 100 |
| | Expanded polystyrene board | |
| | Concrete | 150 |
| **Window** | Glazing | |
| | Frame | 25 |

Tab. 2: Construction layers of each building element in the simulation model

- *Window control:* Since the intention is to naturally ventilate the building as much as possible, windows are opened when required. The dry bulb temperature of the appropriate zone controls the window opening. A window proportion of 30% is opened when the dry bulb temperature in the zone exceeds 24°C; they are fully opened when the dry bulb temperature reaches 25°C. The apertures close when the external temperature exceeds the internal temperature.

| Customer requirement | Glass mineral wool | Rock mineral wool | Extruded polystyrene | Expanded polystyrene | PUR and PIR |
|---|---|---|---|---|---|
| **Thermal performance** | high | medium | high | high | extra high |
| **Cost** | low | medium | lower | lower | high |
| **Sound absorption** | high | high | none | none | none |
| **Fire resistance** | non-combustible | non-combustible | combustible | combustible | combustible |
| **Compressive strength** | low | medium (suitable for some floors) | high (suitable for all floors) | medium (suitable for some floors) | medium (suitable for some floors) |
| **Water resistance** | high | high | very high | high | high |
| **Weight** | very light to medium | light to heavy | medium | medium | medium |
| **Warehousing space requirements** | very low (8:1 packaged compression) | medium (2.5:1 packaged compression) | very high | medium to high | medium to high |
| **Transport efficiency** | very good | good | medium | low | low |
| **Handling in construction** | not easy | not easy | easy | easy | easy |
| **Embodied energy** | low | low | medium | high | very high |
| **Environmental production hazards** | none | none | too high | none | none |
| **Possibilities of reuse** | low | low | low | high | high |
| **Environmental waste impact** | low | low | easy | high | high |

Tab. 3: Comparison between different types of insulating material

- *Shading:* In the climatic conditions of Hashtgerd with relatively high solar radiation, solar control is extremely important. In the TAS model, external blinds with a solar transmittance of as much as 0.416 and a light transmittance of 0.52 are applied to all external transparent elements during the summer months when solar radiation is not required.

**Parametric studies**

Four sets of parametric tests were conducted to estimate the potential energy savings of additional thermal insulation in office constructions. The heating and cooling demand of the New Generation Office Building was extracted from the simulation results in each test for a whole year. The tests differ in the choice of window material and the usage of natural ventilation. Table 4 shows the difference between the four parametric test series.

| Test 1 | Test 2 | Test 3 | Test 4 |
|---|---|---|---|
| Windows open (naturally ventilated) | Windows closed (air conditioned) | Windows open (naturally ventilated) | Windows closed (air conditioned) |
| In better insulated models (cases 3 to 9), windows are double-glazed. | | In better insulation (cases 3 to 9), windows are with low-e double glazing. | |

Tab. 4: Differences between the four parametric tests

Table 5 shows the U-values of different building elements and the building mean U-value for each simulated case in all tests.

Tab. 5: Differences between the four parametric tests

| Case study | Mean U-value (W/m²C) Tests 1,2 | Tests 3,4 | Building element | U-value (W/m²C) Tests 1,2 | Tests 3,4 | Insulation thickness (mm) |
|---|---|---|---|---|---|---|
| **1** (typical construction) | 2.85 | not tested | External wall | 1.75 | | 0 |
| | | | Roof | 1.12 | | 0 |
| | | | Ground floor | 3.44 | | 0 |
| | | | Exposed floor | 1.19 | | 0 |
| | | | Window glazing | 5.80 | | |
| | | | Window frame | 5.88 | | |
| **2** (Code 19) (Office to develop and promote national building regulations, 2002) | 2.66 | not tested | External wall | 1.61 | | 2 |
| | | | Roof | 0.81 | | 14 |
| | | | Ground floor | 3.44 | | 0 |
| | | | Exposed floor | 0.81 | | 16 |
| | | | Window glazing | 2.86 | | |
| | | | Window frame | 2.85 | | |
| **3** | 2.13 | 1.82 | External wall | 1.61 | same | 2 |
| | | | Roof | 0.81 | same | 14 |
| | | | Ground floor | 3.44 | same | 0 |
| | | | Exposed floor | 0.81 | same | 16 |
| | | | Window glazing | 2.86 | 1.29 | |
| | | | Window frame | 2.85 | 2.34 | |
| **4** | 2.01 | 1.71 | External wall | 1.39 | same | 6 |
| | | | Roof | 0.60 | same | 30 |
| | | | Ground floor | 3.44 | same | 0 |
| | | | Exposed floor | 0.60 | same | 33 |
| | | | Window glazing | 2.86 | 1.29 | |
| | | | Window frame | 2.85 | 2.34 | |
| **5** | 1.46 (50% better insulated than code 19) | 1.15 | External wall | 0.93 | same | 20 |
| | | | Roof | 0.40 | same | 65 |
| | | | Ground floor | 2.00 | same | 8 |
| | | | Exposed floor | 0.40 | same | 66 |
| | | | Window glazing | 2.86 | 1.29 | |
| | | | Window frame | 2.85 | 2.34 | |
| **6** | 1.24 | 0.93 | External wall | 0.70 | same | 34 |
| | | | Roof | 0.30 | same | 100 |
| | | | Ground floor | 1.50 | same | 15 |
| | | | Exposed floor | 0.30 | same | 100 |
| | | | Window glazing | 2.86 | 1.29 | |
| | | | Window frame | 2.85 | 2.34 | |
| **7** | 1.05 | 0.74 | External wall | 0.50 | same | 58 |
| | | | Roof | 0.21 | same | 160 |
| | | | Ground floor | 1.06 | same | 26 |
| | | | Exposed floor | 0.21 | same | 160 |
| | | | Window glazing | 2.86 | 1.29 | |
| | | | Window frame | 2.85 | 2.34 | |
| **8** | 0.96 | 0.65 | External wall | 0.40 | same | 77 |
| | | | Roof | 0.17 | same | 200 |
| | | | Ground floor | 0.86 | same | 35 |
| | | | Exposed floor | 0.17 | same | 200 |
| | | | Window glazing | 2.86 | 1.29 | |
| | | | Window frame | 2.85 | 2.34 | |
| **9** | 0.80 | 0.48 (EnEV 2009) | External wall | 0.26 | same | 130 |
| | | | Roof | 0.19 | same | 180 |
| | | | Ground floor | 0.35 | same | 104 |
| | | | Exposed floor | 0.20 | same | 170 |
| | | | Window glazing | 2.85 | 1.29 | |
| | | | Window frame | 0.26 | 2.34 | |

## Results and discussion

### *Test 1*

The heating and cooling loads as well as the total load of the simulated cases in test 1 are shown in table 6 and figure 43.

| Case study | Mean U-value (W/m²°C) | Heating load (kWh/m²a) | Cooling load (kWh/m²a) | Total load (kWh/m²a) |
|---|---|---|---|---|
| 1 | 2.85 | 23.9 | 14.9 | 38.8 |
| 2 | 2.66 | 20.9 | 14.9 | 35.8 |
| 3 | 2.13 | 13.0 | 15.7 | 28.7 |
| 4 | 2.01 | 11.4 | 15.8 | 27.2 |
| 5 | 1.46 | 8.9 | 16.4 | 25.3 |
| 6 | 1.24 | 7.8 | 16.7 | 24.5 |
| 7 | 1.05 | 6.7 | 16.9 | 23.6 |
| 8 | 0.96 | 6.3 | 17.1 | 23.4 |
| 9 | 0.80 | 5.8 | 17.6 | 23.4 |

Tab. 6: Energy demands in naturally ventilated NG Office Building with different thicknesses of thermal insulation

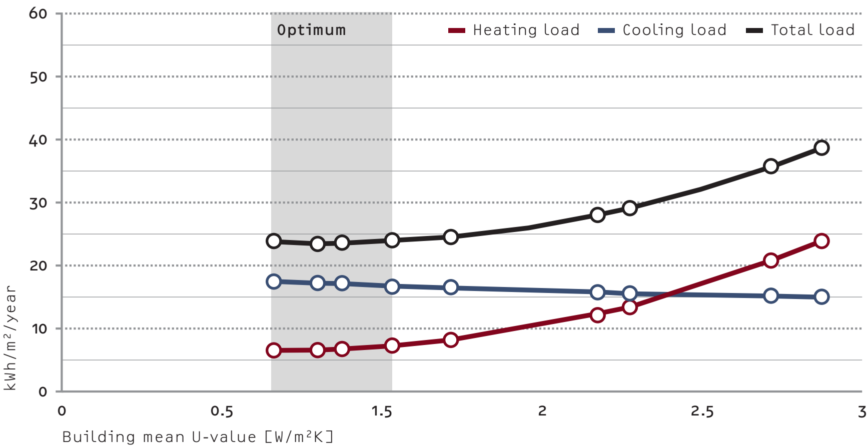



Fig. 43: Effect of thermal insulation on the heating, cooling, and total loads in naturally ventilated NG Office Building

According to the graph, there is a dramatic fall in the need for heating energy as a result of the better insulated building envelope. The heating load of the New Generation Office Building decreases as much as 13% compared to the average construction (without insulation) if the insulation is based on Code 19. The decline continues until it gets to around 54% below the Code 19 case (case 2), which is the case with an almost 50% better U-value than that of Code 19 (case 5). The heating demand reaches its lowest point in the final case

(case 9) with an approximately 70% decrease compared to that of the Code 19 case. As the insulation increases, the slope of the trend is less significant.

On the other hand, the cooling load rises as the thermal insulation increases. Although there is no difference between the cooling demand of the average construction and the Code 19 case, the New Generation Office Building requires, respectively, 10% and 18% more energy for cooling as the thermal insulation increases to that of the cases 5 and 9. In contrast to the heating graph, the slope of the cooling graph increases more dramatically as a result of better thermal insulation. In view of global warming and the increase of cooling demand as an effect of better thermal insulation, special cooling strategies should be considered if more insulation is to be used to reduce the heating load.

The total energy consumption, though, more or less follows the trend of the heating load. However, it becomes almost constant when it gets to the last four cases, which shows that the positive effect of even better insulation is less significant in the relatively well insulated cases.

**Test 2**

Table 7 and Figure 44 show the results of test 2, including the heating, cooling and total loads for the New Generation Office Building with all windows closed throughout the day since the building is fully air conditioned.

| Case study | Mean U-value (W/m²°C) | Heating load (kWh/m²a) | Cooling load (kWh/m²a) | Total load (kWh/m²a) |
|---|---|---|---|---|
| 1 | 2.85 | 23.9 | 25.4 | 49.3 |
| 2 | 2.66 | 20.9 | 25.7 | 46.6 |
| 3 | 2.13 | 13.0 | 30.8 | 43.8 |
| 4 | 2.01 | 11.4 | 31.7 | 43.1 |
| 5 | 1.46 | 8.9 | 34.3 | 43.2 |
| 6 | 1.24 | 7.8 | 35.9 | 43.7 |
| 7 | 1.05 | 6.7 | 37.6 | 44.3 |
| 8 | 0.96 | 6.3 | 38.6 | 44.9 |
| 9 | 0.80 | 5.8 | 41.1 | 46.9 |

Tab. 7: Energy demands in the air conditioned NG Office Building with different thicknesses of thermal insulation

Figure 44 shows that the heating demand does not change, as expected, while there is a considerable change in the trend of the cooling load. There is a sharp increase in the cooling demand of the New Generation Office Building as a result of more insulation. In other words, the cooling load of the building increases as much as 60% from case 1 to case 9 whereas the increase was only 18% in test 1.

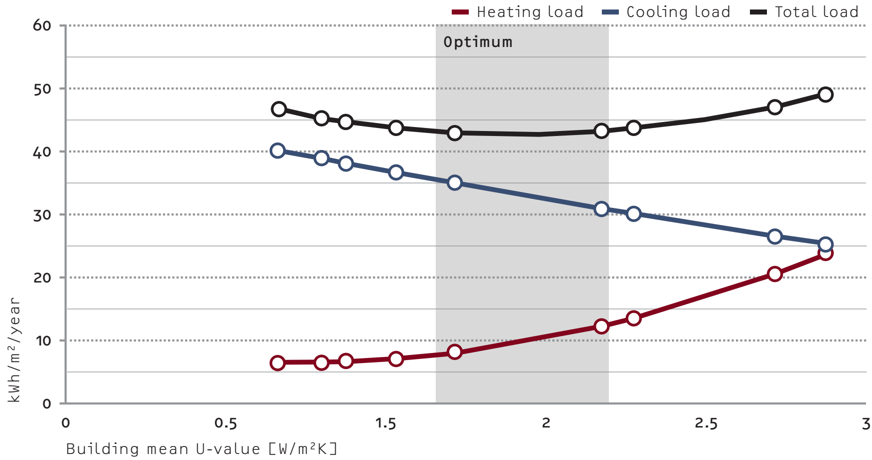



Fig. 44: Effect of thermal insulation on the heating, cooling and total loads in the fully air conditioned NG Office Building

This significant change in the cooling load means that the total energy demand is best between the cases 4 to 5. This shows that if the New Generation Office Building is to be air-conditioned at all times, better insulation than case 5 will have a negative effect on both the cooling and total load.

**Test 3**

In tests 3 and 4, the glazing material of the windows is replaced by low-e double glazing and the window frame is made of wood with a better thermal resistance. These tests are undertaken to examine the effect of applying low-e glazing to optimize the U-value of the opaque external building elements. The other building elements have the same U-values as in the tests 1 and 2. The test results are illustrated in table 8.

In order to understand the differences achieved by applying low-e glass, the figures 45 to 47 compare each the loads of test 3 and test 1 separately.

| Case study | Mean U-value ($W/m^2 °C$) | Heating load ($kWh/m^2a$) | Cooling load ($kWh/m^2a$) | Total load ($kWh/m^2a$) |
|---|---|---|---|---|
| 3 | 1.82 | 11.9 | 9.9 | 21.8 |
| 4 | 1.71 | 10.3 | 9.9 | 20.2 |
| 5 | 1.15 | 7.7 | 10 | 17.7 |
| 6 | 0.93 | 6.6 | 10.1 | 16.7 |
| 7 | 0.74 | 5.5 | 10.1 | 15.6 |
| 8 | 0.65 | 5.1 | 10.2 | 15.3 |
| 9 | 0.48 | 4.5 | 10.5 | 15.0 |

Tab. 8: Energy demands in naturally ventilated NG Office Building with low-e windows and different thicknesses of thermal insulation

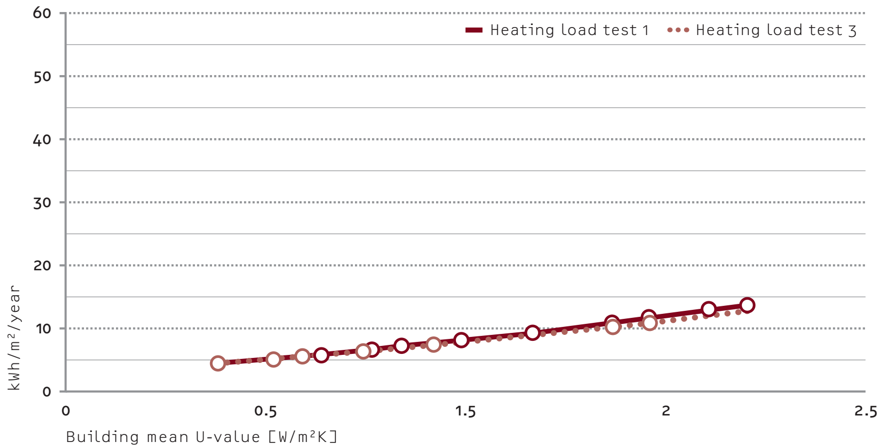



Fig. 45: Comparison of the effects of thermal insulation on the heating loads in the naturally ventilated NG Office Building with double glazed windows (test 1) and with double glazed low-e windows (test 3)

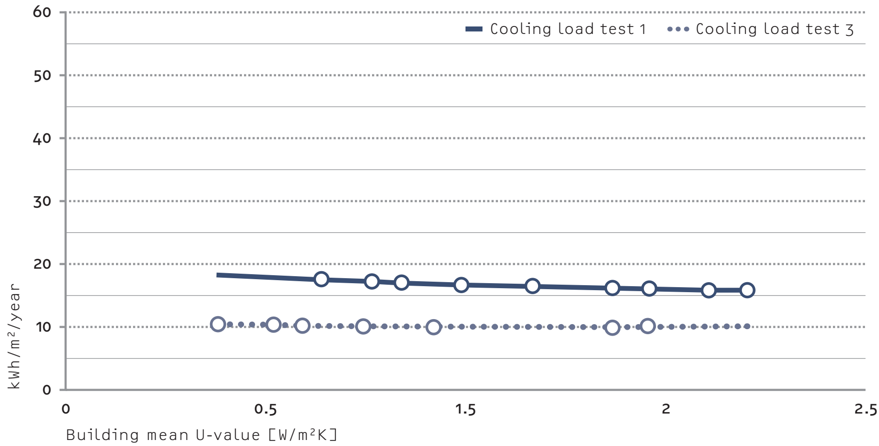



Fig. 46: Comparison of the effects of thermal insulation on the cooling loads in naturally ventilated NG Office Building with double glazed windows (test 1) and with double glazed low-e windows (test 3)

The trend of the heating loads is similar in both tests with negligible differences while there is a significant change in the cooling demand of the building as a result of having low-e windows (Figures 45 and 46). There is a considerable reduction in the cooling demand of the building in test 3 compared to test1, and the rising trend of the cooling demand in test 1 changes to an almost constant trend with little differences in the cooling demand of all tested cases in test 3. This can be explained by looking at table 9.

According to this table, the solar transmittance of the low-e windows in test 3 is 20% less than that of the double glazing material in tests 1 and 2.

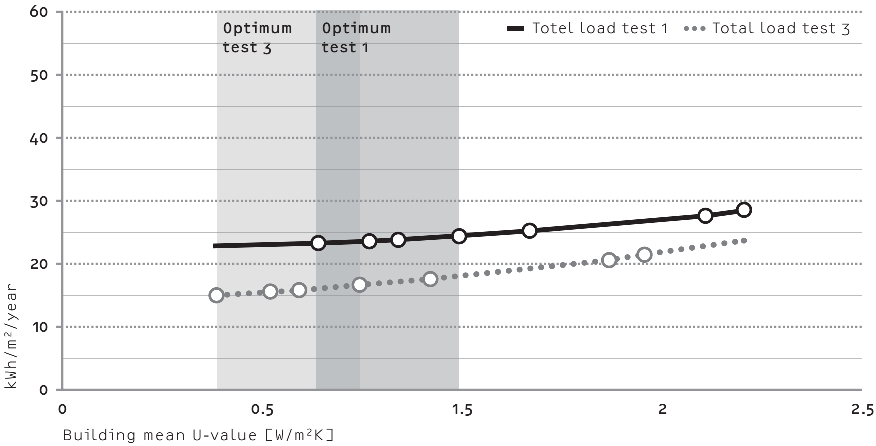



Fig. 47: Comparison of the effects of thermal insulation on the total loads in the naturally ventilated NG Office Building with double glazed windows (test 1) and with double glazed low-e windows (test 3)

| | Window type | Solar trans-mittance | External solar absorptance Ext. surf | Int. surf |
|---|---|---|---|---|
| **Tests 1,2** | Inner: 6 mm optical clear glass | 0.643 | 0.117 | 0.123 |
| | 12 mm air | | | |
| | 4 mm optical clear glass | | | |
| **Tests 3,4** | Inner: 4mm clear glass | 0.510 | 0.314 | 0.060 |
| | 16 mm argon | | | |
| | 4 mm clear glass (low-e) | | | |

Tab. 9: Comparison of window types in tests 1, 2 with the ones in tests 3, 4

In addition, low-e windows have about 170% more solar absorptance on the external surface. This means that solar radiation is absorbed better by the low-e window and not transmitted to the inside of the building in test 3. This is the reason for the lower cooling demand and the constant trend in test 3.

As a result of the considerable reduction in the cooling demand, the total energy demand of the New Generation Office Building is less in test 3 than in test 1 (Figure 47).This means that better insulation of the opaque building envelope has a more positive effect on reducing the energy consumption of the building when low-e windows are used.

***Test 4***

In this test, the building with all specifications of test 3 is simulated with closed windows. The heating, cooling and total demands of the building are shown in table 10.

| Case study | Mean U-value (W/m²°C) | Heating load (kWh/m²a) | Cooling load (kWh/m²a) | Total load (kWh/m²a) |
|---|---|---|---|---|
| 3 | 1.82 | 11.9 | 18.4 | 30.3 |
| 4 | 1.71 | 10.3 | 18.5 | 28.8 |
| 5 | 1.15 | 7.7 | 19.4 | 27.1 |
| 6 | 0.93 | 6.6 | 20.0 | 26.6 |
| 7 | 0.74 | 5.5 | 20.7 | 26.2 |
| 8 | 0.65 | 5.1 | 21.1 | 26.2 |
| 9 | 0.48 | 4.5 | 22.8 | 27.3 |

Tab. 10: Energy demands in the air conditioned NG Office Building with low-e windows and different thicknesses of thermal insulation

To understand how the application of low-e windows can change the results of test 2, figures 48 and 49 illustrate comparative graphs for both the cooling and the total loads. According to these graphs, almost the same changes occur in the building with closed windows (without simple natural ventilation) as with open windows (naturally ventilated). In other words, the cooling demand reduces dramatically with minimum differences between the tested cases. Consequently, the total load is much less than in test 2, showing greater reductions and moving the optimum cases towards the more insulated ones.

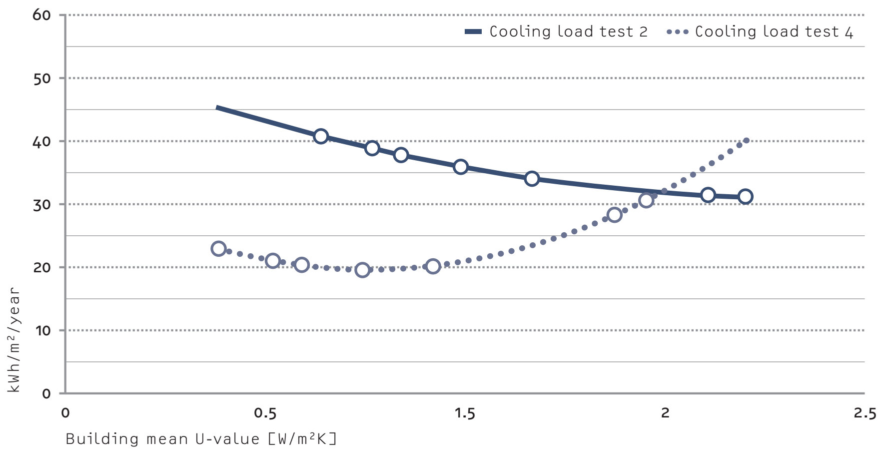



Fig. 48: Comparison of the effect of thermal insulation on the cooling loads in the air conditioned NG Office Building with double glazed windows (test 2) and with double glazed low-e windows (test 4)

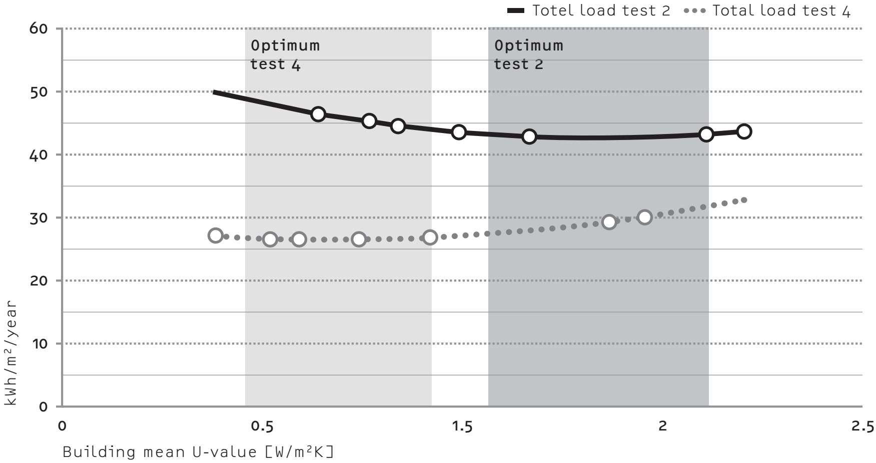



Fig. 49: Comparison of the effect of thermal insulation on the total loads in the air conditioned NG Office Building with double glazed windows (test 2) and with double glazed low-e windows (test 4)

## Conclusion

To conclude, Code 19 does not appear to be efficient enough for the New Generation Office Building and more insulation is recommended in consideration of the total energy requirements.

There is a significant difference between the naturally ventilated and the fully air-conditioned buildings in terms of thermal insulation. Natural ventilation (open windows in tests 1 and 3) minimizes the negative effects of insulation on the thermal behavior of the building during summer, which in turn allows a better insulated envelope to reduce the heating demand in winter. However, in fully air-conditioned buildings, where the windows are always closed, good thermal insulation leads to a greater increase of the cooling demand than the decrease of the building's heating requirements. This is because in a fully air conditioned building, the heat is trapped inside and cannot be dissipated to the outdoor air, which results in a warmer interior and a greater need for cooling.

If low-e windows are used in the building, the outcome is different. There is a considerable reduction in the total energy consumption of the building as a result of the significant reduction of the cooling demand and the minimization of the negative effects on the cooling loads caused by more thermal insulation.

## 2.5 Cost analysis

Having studied the heating and cooling demands individually through simulations, cost is another important factor to be considered in defining the optimum thermal insulation. In this study, all costs associated with each solution, including the initial costs, the energy and life cycle costs, are calculated for a period of 15 years to provide an economic evaluation of the different cases.

The associated costs are only calculated for the New Generation Office Building with the specifications of test 1. But in each part of the analysis, the building with low-e windows, as applied in test 3, is analyzed by performing a comparison with test 1.

**Required data**

The following items were considered in the calculation of the associated costs:

- Nominal discount rate: The discount rate is the interest that makes the investor indifferent to the cash amounts received at different points in time. The nominal discount rate is officially announced and is set at 14%, as published by the Money & Credit Council (Shoraye Pool o Etebar) for the year 2011 (Rajanews website, 16 March 2011).
- Inflation rate: Inflation is a rise in the general level of prices for goods and services over a period of time. According to the Statistical Centre of Iran (Markaz Amar Iran), the inflation rate was 19.6% for the 12-month period up until July 2011 (Khabaronline website, 17 August 2011).
- Price escalation rate: Price escalation is the rise in the cost of energy and water over a period of time. Since the rise in the cost of energy is not predictable in Iran's current situation, it is considered to be the same as the inflation rate in this research study.
- Real discount rate: The real discount rate is the real earning power of money in consideration of the general inflation rate. According to research into the nominal discount rate and the inflation rate, the real discount rate is -5.6% (nominal discount rate - inflation rate = real discount rate).
- Real price escalation rate: The real price escalation rate is the increase in the cost of energy after removing the impact of general inflation. Since the same value is applied to the inflation rate and the price escalation rate, the real price escalation rate is zero in this study.
- Energy consumption: The energy consumption is required to calculate the energy costs and is obtained from the EDSL TAS simulation outputs. The heating demand is considered as fossil fuel consumption because the majority of heating systems in Iran operate with gas. Similarly, the electricity consumption is assumed to be equal to the cooling demand since most cooling systems in Iran operate with electricity. Because the only difference between the case studies is the mean U-value of the building,

the electricity used for artificial lighting, cooking, and appliances is not considered in the calculations.

- Energy costs: The energy costs have been extracted from the gas and electricity bills of the current Hashtgerd branch of the New Town Development Corporation (NTDC) office building. Because the gas price was applied for m³, there was need to convert it into kWh so that it could be comparable with the electricity price. The conversion rate specific to Iran was not identified; thus, the rate used in the UK, 1 m³ = 11 kWh (Energylinx website, 2011) was used. Accordingly, the price of gas was set at 190 IRR/kWh (0.013 EUR/kWh[1]) and the price of electricity at 1,560 IRR/kWh (0.106 EUR/kWh[2]).
- Construction costs: At first the initial costs for each solution were identified. A report prepared by the Central Bank of the Islamic Republic of Iran (2011) shows that the average construction costs for non-domestic buildings was 5,101,137 IRR/m² (348 EUR/m²) in the second three months of 2010. Considering an inflation rate of 19.6%, this amount is 6,100,359 IRR/m² (416 EUR/m²) for the same period of 2011. This is assumed to be the cost of a typical building in Iran which is built without thermal insulation and with single glazed windows. The costs of thermal insulation and glazing materials are based on the latest price list for construction works in Iran (2009). It defines the construction costs for the second 3 months of 2009 and the price adjustment indices for 2010 and 2011 (Strategic Planning & Control organization, 2010 and 2011). To calculate the construction costs for each case, the costs of thermal insulation and glazing materials are added to the base construction costs of the New Generation Office Building with typical constructions.
- Maintenance costs: These costs concern all aspects of regular maintenance work, including building systems and all building components. It is assumed to be 2% of the initial costs.
- Replacement costs: This category includes any costs for the regular replacement of building systems and components up until the end of their design life. This is considered to be zero in this research study.

## Results and discussion

### *Initial cost analysis*

The initial costs for each case in test 1 were calculated according to data from the previous section. The results are shown in table 11.

Based on the data in table 11, there is a 0.38% rise in the initial costs of the New Generation Office Building if it is to be thermally insulated according to Code 19. Improving the thermal insulation and achieving a better building mean U-value of 0.80W/m²°C results in a 1.02% increase of the initial building costs above those of Code 19.

The application of double glazed low-e windows, instead of double glazed windows, results in higher initial costs, simply since low-e windows cost more.

| Case study | Building mean U-value (W/m²°C) | Initial costs (IRR) | Initial costs (EUR) |
|---|---|---|---|
| 1 | 2.85 (typical building) | 19,649,256,340 | 1,338,870 |
| 2 | 2.66 (Code 19) (Office to develop and promote national building regulations, 2002) | 19,723,162,220 | 1,343,906 |
| 3 | 2.13 | 19,753,118,470 | 1,345,947 |
| 4 | 2.01 | 19,762,707,560 | 1,346,600 |
| 5 | 1.46 (50 % better insulated than Code 19) | 19,789,789,460 | 1,348,446 |
| 6 | 1.24 | 19,815,393,640 | 1,350,190 |
| 7 | 1.05 | 19,855,817,240 | 1,352,945 |
| 8 | 0.96 | 19,885,145,610 | 1,354,943 |
| 9 | 0.80 | 19,925,137,630 | 1,357,668 |

Tab. 11: Initial costs for each case study of test 1

### *Energy cost analysis*

Both the gas and electricity costs were calculated for a 15-year period in consideration of the inflation, real discount and real escalation rates. The cost of energy used for heating and cooling the building is the sum of gas and electricity costs. As illustrated in table 12, there is a significant decrease of as much as 75% in gas costs between cases 1 and 9. In contrast, the electricity costs increase continuously as a result of larger insulated building envelope areas. These two opposite trends reach a minimum at a building mean U-value of 2.01 W/m²°C. Whereas the heating costs for case 4 of the New Generation Office Building are reduced by as much as 45% by using additional insulation, compared to the Code 19 building, the electricity costs increase by only 6%.

This reveals that in the warm and dry climate of Hashtgerd New Town, thermal insulation is not always an advantage for the building economy as there are two extreme seasons; a building with a larger area of insulated envelope has lower energy costs in winter, but higher electricity costs during the summer months. Although the reduction of the heating energy demand is much greater than the increase of the cooling energy demand, as a result of the thermal insulation, the use of electricity for cooling, which costs more than eight times as much as gas for heating, has a considerable effect on the total energy costs (electricity at 0.106 EUR/kWh is about eight times more expensive than gas at 0.013 EUR/kWh). It is also clear from the table that, according to the energy costs, it is desirable for the insulation of the New Generation Office Building to reach a better value than that of Code 19, up to a building mean U-value of 2.01 W/m²°C; although, provisions should then be

| Case study | Building mean U-value (W/m²°C) | Gas costs (IRR) | Gas costs (EUR) | Electricity costs (IRR) | Electricity costs (EUR) | Energy costs (IRR) | Energy costs (EUR) |
|---|---|---|---|---|---|---|---|
| 1 | 2.85 | 23.9 | 25.4 | 1,128,073,500 | 76,865 | 1,348,456,300 | 91,882 |
| 2 | 2.66 | 20.9 | 25.7 | 1,128,073,500 | 76,865 | 1,320,793,220 | 89,997 |
| 3 | 2.13 | 13.0 | 30.8 | 1,188,645,780 | 80,992 | 1,308,519,110 | 89,160 |
| 4 | 2.01 | 11.4 | 31.7 | 1,196,214,380 | 81,508 | 1,301,332,930 | 88,671 |
| 5 | 1.46 | 8.9 | 34.3 | 1,241,625,960 | 84,602 | 1,323,693,370 | 90,194 |
| 6 | 1.24 | 7.8 | 35.9 | 1,264,355,260 | 86,151 | 1,336,279,830 | 91,052 |
| 7 | 1.05 | 6.7 | 37.6 | 1,279,492,450 | 87,183 | 1,341,274,180 | 91,393 |
| 8 | 0.96 | 6.3 | 38.6 | 1,294,629,640 | 88,214 | 1,352,721,240 | 92,172 |
| 9 | 0.80 | 5.8 | 41.1 | 1,353,621,600 | 92,234 | 1,407,952,040 | 95,936 |

Tab. 12: Gas, electricity and total energy costs in each case study of test 1

made to minimize the associated negative effects during the summer period.

Using low-e windows in the New Generation Office Building means that the optimum case in regard of energy costs is closer to the better insulated buildings, since the cooling demand does not increase significantly as a result of more insulation.

### *Life cycle cost (LCC) analysis*

A life cycle cost (LCC) analysis is a valuable method to predict, assess and evaluate the total costs of a product or service at an early design stage. It enables the comparison of solutions with different cash flows and different time frames and provides sufficient information for decision makers in the selection process (Fuller, 2010).

| Case study | Building mean U-value (W/m²°C) | Life cycle costs (IRR) | Life cycle costs (EUR) |
|---|---|---|---|
| 1 | 2.85 | 26,918,930,170 | 1,834,214 |
| 2 | 2.66 | 26,987,444,190 | 1,838,883 |
| 3 | 2.13 | 27,014,153,510 | 1,840,703 |
| 4 | 2.01 | 27,019,446,050 | 1,841,063 |
| 5 | 1.46 | 27,077,049,410 | 1,844,988 |
| 6 | 1.24 | 27,122,955,750 | 1,848,116 |
| 7 | 1.05 | 27,180,555,170 | 1,852,041 |
| 8 | 0.96 | 27,230,168,590 | 1,855,422 |
| 9 | 0.80 | 27,432,636,160 | 1,869,218 |

Tab. 13: Life cycle costs in each case study of test 1

LCC, including the initial, maintenance and energy (in this study heating and cooling energy) costs, were also calculated for a 15-year period (Table 13).

In spite of the initial expectations of well-insulated cases having lower LCC, compared to the typical case, the LCC increases from case 1 to 9. The key reasons can be extracted from table 14, which shows the percentages of each LCC cost item.

| Case study | Initial costs (%) | Maintenance costs (%) | Energy costs (%) | Life cycle costs (%) |
|---|---|---|---|---|
| 1 | 72,99 | 22,00 | 5,01 | 100,00 |
| 2 | 73,08 | 22,02 | 4,90 | 100,00 |
| 3 | 73,12 | 22,04 | 4,84 | 100,00 |
| 4 | 73,14 | 22,04 | 4,82 | 100,00 |
| 5 | 73,09 | 22,02 | 4,89 | 100,00 |
| 6 | 73,06 | 22,01 | 4,93 | 100,00 |
| 7 | 73,05 | 22,01 | 4,94 | 100,00 |
| 8 | 73,02 | 22,01 | 4,97 | 100,00 |
| 9 | 72.63 | 22.24 | 5.13 | 100,00 |

Tab. 14: Contribution of each cost item in percent from the total life cycle costs

The only item that leads to a reduction of the LCC is the energy costs, since they decrease from case 1 to 4, while both the initial and maintenance costs increase from case 1 to 9. As the energy cost item is a small percentage of the LCC, around 5%, it cannot compensate for the other associated building costs even after 15 years. The reasons for the low percentage of energy costs are the low energy demand of the New Generation Office Building and the still very low energy prices, in spite of recent increases.

Another important factor is the negative real discount rate and the zero real escalation rate that make any investment, including investments in the building and energy sector, unprofitable in Iran's current economic situation. In other words, the inflation rate is higher than the nominal discount and the price escalation rates, which reduces the real value of money over time.

**Conclusion**

Although it is believed that the development of low-energy buildings and the reduction of their $CO_2$ emissions is a promising solution to mitigate climate change, solutions also have to be economically profitable if they are to be practiced in the whole building market. The cost analysis studies for the New Generation Office Building in Iran show that the investment in a better thermally insulated building envelope does not result in financial profits over time in spite of the reduced energy costs for some of the better insulated cases. The reasons revealed are the low energy consumption of the building, the still low energy prices, the high inflation rate and the low real discount and real price escalation rates.

Therefore, there should be financial incentives, such as low-interest loans, subsidized thermal insulation and double-glazed windows, etc. in the building market to encourage developers and builders to invest in better thermally insulated building envelopes.

Finally, the appropriate criterion to decide on the optimum U-value of the New Generation Office Building should be the energy costs and not the life cycle costs. The key reason for this recommendation is that energy is an important requirement, especially in developing countries like Iran; therefore, any monetary saving in this respect is of benefit for the whole country.

## 2.6 Conclusions

In the two previous chapters, the analysis of the findings has been discussed in detail. This chapter is intended to briefly draw together the main conclusions of the study.

The study highlights the importance of creating a thermal-resistant building envelope in the New Generation Office Building and performing an analysis in consideration of both the energy consumption and the associated costs.

From an energy point of view, the thermal insulation has a considerable positive effect on reducing the heating demand of the New Generation Office Building. However, it can have a negative effect of increasing the cooling energy demand as a result of greater insulated areas in the envelope. The rise in cooling load, however, is not as significant as the decrease in heating demand. Therefore, the optimum case is a relatively well insulated building. The application of natural ventilation and low-e windows reduces the negative impacts of thermal insulation on the cooling demand and thus the total energy load.

On the other hand, from a cost point of view, the result is completely different. A better insulated envelope requires a higher initial investment, which is not beneficial in the Iranian market, even after a 15-year period. This is the situation for several insulated cases despite the reduction of energy costs.

The key reasons for the higher costs have been revealed as the high inflation rate, the low real discount and price escalation rates, the low energy demand of the New Generation Office Building as well as the low energy costs in general. There are no monetary benefits in investigating in more thermal-resistant building envelopes in spite of their energy-saving and environmental benefits.

In other words, the cost analysis has shown that having a high thermal-resistant envelope as a passive strategy to reduce energy consumption in the New Generation Office Building is only financially beneficial in a country with a stable economic background, including low inflation rates and high discount and price escalation rates that make an investment financially profitable over a longer period of time. In more secure economic situations, high energy costs could be an effective motivator to encourage low-energy strategies in the building sector including more thermal-resistant building envelopes.

Table 15 shows the optimum U-value from each part of the study with the associated thermal insulation thickness in each envelope element.

| **Optimum U-value (W/m2°C)** | | **Thermal insulation thickness (mm)** Ext. wall | Roof | Exposed floor | Ground floor |
|---|---|---|---|---|---|
| 1.24 | Naturally ventilated NGOB with DG | 34 | 100 | 100 | 15 |
| 2.01 | Air-conditioned NGOB with DG | 6 | 30 | 33 | 0 |
| 0.93 | Naturally ventilated NGOB with low-e DG | 34 | 100 | 15 | 100 |
| 1.15 | Air-conditioned NGOB with low-e DG | 20 | 65 | 8 | 66 |
| 2.85 | LCC analysis | 0 | 0 | 0 | 0 |
| 2.01 | Energy cost analysis in naturally ventilated NGOB with DG | 6 | 30 | 33 | 0 |

Tab. 15: Optimum U-value in each study and associated thermal insulation thickness for each envelope element

In the current economic situation of Iran, financial incentives, such as low interest loans for builders and developers along with improved building policies, are the only effective way to encourage more efficient building envelopes. In the case of the New Generation Office Building and similar projects, if these are to function as prototypes of low energy buildings in Iran, the investment should not be aimed at immediate financial benefits, but long-term economic, scientific and social benefits in the Iranian building sector.

Considering all the above-mentioned aspects, the decision on defining the optimum thermal resistance of the building envelope in the New Generation Office Building should be taken as a basis for the amount of financial support offered to the builder of the project.

In summary, the following points concerning the New Generation Office Building are:

- LCC is not an appropriate criterion to define the amount of thermal insulation. Financial support and incentives are needed to encourage builders to construct thermal-resistant buildings.
- Insulating better than Code 19, up to building mean U-value (BMU) of around 2 W/m²C, is only beneficial in consideration of both the energy consumption and the energy costs.

- In the case of natural ventilation and low-e double glazed windows, the more thermal insulation than BMU 2 W/m²C, the better the results for both the energy demand and the energy costs. The optimum BMU is 0.5–2 W/m²C.

The final decision concerning the optimum amount of thermal insulation depends on the available budget and the financial aids for the construction.

**Limitations of the research**

A number of limitations have affected the results of the study:

- The study lacks an energy benchmark to provide a basis for comparison in the energy studies. This benchmark should have been the energy consumption of either a typical or a best practice office building in Iran, none of which were available at the time of research.
- The cost analysis was performed according to official data from relevant Iranian organizations. However, some of the data is not based on real figures. As an example, the inflation rate for the current year (2011) is believed to be much higher than the amount officially announced (Deutche Welle website, 16 August 2011). Similarly, the construction material costs are thought to be higher in the building market than what is shown in the official price lists.
- The price escalation rate, which shows the rise in the cost of energy, was not available for Iran at the time of the study. Subsidies in the energy sector had recently been removed, causing the energy prices to rise significantly; whether or not further dramatic rises are to be expected in the energy sector is not clear. Thus, the price escalation rate was not foreseeable at the time of the study. The research work, therefore, uses the inflation rate for the price escalation rate, which is obviously only an assumption.

[1, 2] 1 EUR = 14,676 IRR (Central Bank of Islamic Republic of Iran website, 15th September 2011)

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